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COURSE IN
Physical Measurements

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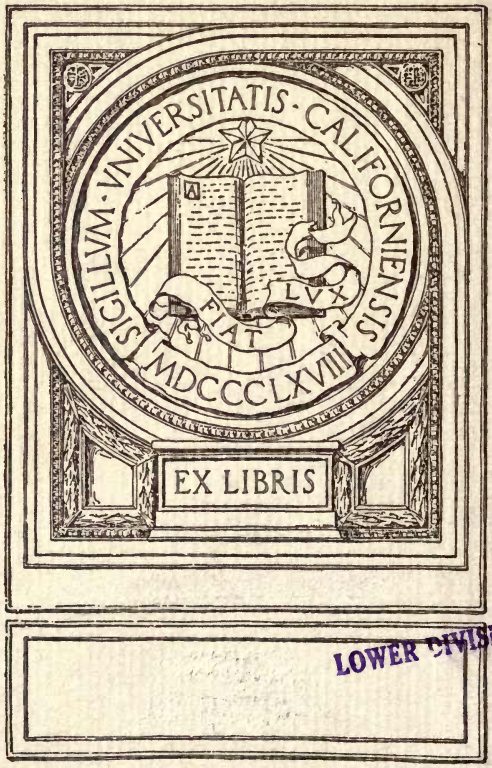
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SOPHOMORE COURSE

IN

PHYSICAL MEASUREMENTS

BY

ELMER R. DREW, B. S.

INSTRUCTOR IN PHYSICS IN THE UNIVERSITY OF CALIFORNIA

BERKELEY, CALIFORNIA

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PREFACE.

THIS Course has been given for the last three years to Sophomore students in the Colleges of Engineering, Chemistry, Agriculture and Natural Sciences, and accompanies a Lecture Course in General Physics. It occupies two 3-hour periods per week throughout the year, being preceded by a Freshman Course of two laboratory periods and one lecture per week for one year, and by a Matriculation Examination in Physics. The students' preparation, as thus indicated, will account for the fact that the present work is confined mainly to directions for handling the apparatus used in the experiments, the theory being either briefly formulated or entirely omitted.

It is intended to so write the exercises that they can not be carried out without much careful thought on the part of the student. In giving them this form, two ideas have been kept in mind: First, not to require of the student anything which his preparation does not warrant; but within this limit, to compel him to build his own steps, with no more guidance than is really necessary. Second, to take nothing on authority; but to have worked out, in some form, the reasoning underlying every method and formula used.

These ideas are further carried out, and results tested, in four written examinations which are held at convenient intervals during the year. When the results show it to be necessary, these examinations are supplemented by recitations and lectures. Rather than say too much in the directions, it is thought best to say too little, encouraging the student to build up his working knowledge of the subject for himself, according to his ability, and then to assist him in properly completing the structure.

Little originality can be claimed for the choice of subject-matter

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for the experiments; but it is hoped that in the sequence in which the exercises are arranged, and in the methods of presenting the details of each experiment, some improvement over the usual texts may be noted. The attempt has been made to have each exercise appear not as an isolated piece of work, but as part of a larger whole, each part depending more or less upon what has preceded it.

In pursuance of this idea, no measurement has been prescribed merely for practice, but always to serve a definite purpose in obtaining a desired result.

The first two experiments, A and B, do not form an integral part of the course, and are assigned only in special cases, to students who are unable to begin the regular sequence of experiments, or are obliged to interrupt it for any reason.

After completing the exercises here laid out, about six periods are spent in what is called "Special Problem Work." Each student is required to select some problem, within his capacity and the facilities of the laboratory, which will occupy the required time. The experimental details and adaptation of apparatus are to be arranged by the student, so far as possible. One of the chief aims of the laboratory course has been to give the power to do independent work of a simple character, and this exercise is a test of the student's ability in that direction.

The author is under obligations to Professor Slate, and all the members of the Physics Department, for advice and constant encouragement during the building up of the Course. He is also especially indebted to Mr. Arthur Incell for skilful assistance in designing and constructing the necessary apparatus, and to Dr. W. P. Boynton for numerous suggestions, the result of his experience in directing the Course during the past year.

E R Drew.

Berkeley, July, 1898.

COURSE IN

Physical Measurements

GENERAL DIRECTIONS.

Each of the following exercises is intended to occupy the time of one laboratory period, unless otherwise stated. There will usually be time, after completing the observations, to calculate and write out the results; but this is not required.

Carbon copies of completed notes and results must be handed in within two weeks of the date on which the experiment was performed. These papers will be marked in the following four grades: 1, excellent; 2, satisfactory; 3, deficient in some part, which will usually be indicated; 4, unsatisfactory as a whole. Papers marked 3 or 4 will be raised to grade 2 if put in satisfactory condition within one week from date of marking; unless this involves repetition of the experiment, when more time will be allowed. Carbon copies only of such corrections will be received.

Papers not handed in within the time limits set above will not be marked higher than grade 3, except in special cases.

All observations should be recorded directly in the notebook. If for any reason it is desirable to take them on loose

paper, they should be copied at once into the book. If any observations are rejected, the reason should be stated.

Neatness and orderly arrangement of notes will be insisted upon. Tabulate numerical data when possible. Always indicate the denominations of numbers. Numerical computations may be merely indicated. Make the explanatory matter full enough so that, when taken in connection with the directions, it will make each step intelligible.

Much time will be saved in numerical work by selecting the method of computation best suited to the particular case, whether logarithms, slide-rule or ordinary arithmetic. A result obtained by one method should always be checked, at least roughly, by some other method.

Never be satisfied with a single reading or determination of a quantity. When circumstances will permit, take at least three readings, varying the conditions and the method of reading as widely as possible.

When two students are working together on an experiment, the work should be so arranged that each observation is taken at least once, usually several times, by each observer. This not only gives each student the full benefit of the experiment, but also tends to eliminate the effect of the so-called "personal equation." The two series of observations should be distinguished by appropriate initials.

In using any piece of apparatus, note the number which will usually be found stamped on some part of it. This is necessary, because the same piece may be needed in a later experiment.

The careful and thoughtful work which this course requires can not be well done in a noisy room. The large number working in the room at once, makes it especially important that each one should carefully avoid making any unnecessary noise, by loud talking or otherwise.

It is of course expected that the tables and apparatus used will be left in good order at the close of the exercise.

A. MAGNIFYING POWER OF TELESCOPE.

Set up a 2-mm. scale in a vertical position, with its divisions in a plane perpendicular to the axis of the telescope, and at a distance of 200 cm. from its object-glass. Focus the telescope on the divisions, by sliding the draw-tube in which the eye-piece is set. It is possible now to see the image in the telescope with one eye, at the same time that the scale itself is seen with the other; and by slightly turning the telescope, if necessary, to see the divisions of the image apparently superposed on those of the scale.

(*a*.) When this can be easily seen, count the number of large divisions and fractions which are covered by one large division of the image. This is the magnifying power of the telescope when used on objects at this distance.

(*b*.) Repeat for distances of 150, 100, 75, 60, 50, 40, and 30 cm. For the shorter distances, use the 1-mm. divisions at one end of the scale.

(*c*.) Plot the results on cross-section paper, using distances as abscissæ and corresponding magnifying powers as ordinates. Draw a curve through the points thus obtained, which will give the magnifying power at any distance within its range.

B. MASS OF GIVEN VOLUME OF AIR.

To determine the mass of a volume of air inclosed in a flask over water.

(*a*.) Mark the water-level in the neck of the flask by means of a mark on a gummed label, and measure its height (h) above the water-level in the beaker.

(*b*.) Read the barometer (see Exp. 2, *a*). From its height (H) and (h), find the pressure on the inclosed air in cm. of mercury.

(*c.*) The inclosed air may be assumed to be saturated with aqueous vapor. Find from No. 15 of Whiting's tables the maximum pressure of aqueous vapor for the working temperature. Subtracting this from (*b*) gives the pressure due to the dry air in the flask.

(*d.*) Empty the flask, wipe off any moisture on the outside, and weigh on trip scales. Fill with water to the mark on the neck, and weigh again. Find from table 22 the volume of 1 gram of water at the working temperature, and calculate the volume of the water, which is that of the air previously inclosed.

Why should the interior of the flask not be dried before weighing it empty?

(*e.*) Using the formula for (W_d) in (*c*), Exp. 2, with the proper pressure substituted for H-f, calculate the mass of the inclosed volume of air.

1. USE OF BALANCE.

Determination of the weight in air of a billiard-ball (celluloid or ivory).

Put the ring in which the ball is to be set to keep it from rolling about, in the left pan, and its counterpoise in the right pan.

(*a.*) Raise the beam of the balance by means of the lever in front. Move the hand near one of the pans if necessary, until the pointer swings over a range of something like ten scale divisions. Then close the case, read and record 5, 7, or any odd number of turning-points of the pointer, in terms of the divisions as numbered on the scale, estimating tenths of the small divisions as closely as possible. Unless successive turning-points differ by a fairly constant amount, showing that the vibration is regularly decreasing, the series should be repeated.

The second observer may read turning-points at the same time, from the rear of the case, by setting up a plane mirror parallel to and facing the scale. Use both eyes, and look on both sides of the central post at once, in order to avoid parallax.

Average the turning-points to the right, and those to the left, separately. The average of these two results is the resting-point of the pointer.

(*b.*) Put the ball in the ring on the left pan, and add weights to the right pan until, on raising the beam, the pointer swings about a point near the middle of the scale. Determine the resting-point.

Always handle the weights with pincers, taking care not to bruise or scratch them. Never change the weights on the pan without first lowering the beam.

(*c.*) Increase or decrease the weights used by two or three

centigrams, so as to move the resting-point toward the center of the scale, then determine this new resting-point. Calculate the change in weight, in milligrams, required to change the resting-point by one scale-division. This is called the sensitiveness of the balance for the load used.

(*d.*) Calculate the true weight of the ball—namely the weights which would give the resting-point found in (*a*). Carry out the result to milligrams, and correct it by applying to the indicated values of the weights used, the corrections given on the box.

(*e.*) The result given above is the weight required, if the balance-arms are of equal length. To test this, weigh the ball in the right pan. Then (G. and S., p. 100) calling the balance arms R and L and the weights of the ball in the corresponding pans W_1 and W_2,

$$R/L = \sqrt{W_1/W_2}$$

and the true weight of the ball, $W = W_2 (R/L)$.

In future weighings with this balance, the ratio of the arms as found above should be used if it differs from unity by an amount great enough to affect the last figure desired in the result.

2. CALIBRATION OF BARODEIK. PART 1.

The Barodeik is an ordinary balance, having a hermetically-sealed flask suspended from one scale-pan, and from the other, as a counterpoise, a glass plate so chosen as to have a surface about equal to the exterior surface of the flask. The reading of the balance pointer on a properly graduated scale gives the density of the surrounding air.

To find the difference between the barodeik reading and the true density of the air.

(*a.*) Set and read the barometer (G. and S., p. 155). The complete setting and reading should be repeated, by each

observer independently, until the readings agree reasonably well, and their average taken.

(*b*.) Read the wet and dry bulb thermometers. Apply corrections to the readings as indicated, and calculate dew-point by the formula given on the instrument. Then from No. 15 of Whiting's tables find the pressure of aqueous vapor in the air, remembering that "dew-point" means the temperature at which the aqueous vapor now in the air would saturate it; or the existing pressure of aqueous vapor in the air would be the maximum pressure if the temperature were lowered to the dew-point.

(*c*.) From (*a*) and (*b*) calculate the density of the air. The mass of one cu. cm. of dry air, at 0° (C) and 76 cm. pressure, is 0.001293 grams. The mass of the same volume of aqueous vapor, under the same conditions, is $\frac{5}{8}$ as much. Then if h be the barometer height, f the pressure of aqueous vapor, and t the temperature, the mass of dry air in 1 cu. cm. of moist air is:

$$W_d = 0.001293 \frac{1}{1+at} \frac{H-f}{76}$$

(a is the coefficient of expansion of a gas.)

And the mass of aqueous vapor in the same volume is:

$$W_v = (\tfrac{5}{8})0.001293 \frac{1}{1+at} \frac{f}{76}$$

The sum of these two is the required density. (Deschanel, p. 400–401.)

(*d*.) Read the barodeik.

Do not touch the instrument, but by moving the hand near one of the scale-pans, set up a small vibration. Then close the case, and determine the resting-point of the pointer, which is the density of the air as indicated by the instrument.

(*e*.) Record the difference between the reading thus obtained and the true density from (*c*), with the proper sign, so

that when added algebraically to the observed reading it will give the true density of the air.

This is the absolute correction for the scale-division to which it applies.

3. CALIBRATION OF BARODEIK. PART 2.

Relative calibration of barodeik scale.

(*a.*) Read the instrument as in Part 1 (*d*). Repeat with a 2 cg. weight on the right-hand scale-pan, then with the same weight on the left scale-pan.

(*b.*) Repeat with a 5 cg. weight.

Finish the observations before beginning the following calculations, so as to make room for those working on Part 1.

(*c.*) Using the exterior volumes of flask and plate, as given on the instrument, calculate the changes in the density of the air which would produce the same effects on the instrument as the putting of the separate weights on the right pan, and on the left pan.

From these results construct a table of corrections, with the proper signs, for the different resting-points observed.

Note that this is a relative calibration. That is, it gives the corrections to be applied to certain readings, as compared with one reading (namely, that when no weights were used), which is assumed correct.

(*d.*) In Part 1, the absolute correction for a certain reading was found. That reading was not far from the one assumed correct above, so the same absolute correction may be applied to the latter. By means of this, convert the table of relative corrections (*c*) into a table of absolute corrections. This completes the absolute calibration of the instrument.

(*e.*) Plot on cross-section paper the readings on the barodeik scale as abscissæ, and the relative corrections of (*c*) as ordinates, but on a much larger scale. Draw a curve through the

plotted points, which will give the correction for any reading on the scale.

Show how the curve can be made to indicate absolute corrections, instead of relative, by moving the horizontal axis of reference up or down by a proper amount. This converts it into an absolute calibration curve for the instrument.

4. WRITTEN EXERCISE.

In place of the regular laboratory exercise, write out the following requirements in the note-book, and hand in copy as usual.

Make the statements clear and complete, and illustrate by diagrams when possible. Ask for assistance on any points which are not understood after a reasonable amount of study.

1. Why is an odd number of turning-points used in determining the resting-point of a balance pointer?

2. Suggest any consideration which would cause the sensitiveness of a balance to change for a change of load.

3. Show that the calculation of the weight in 1(*d*) is simply a process of interpolation.

4. Show that the method used for finding the resting-point of a balance pointer gives a better result than could be obtained by reading the position of the pointer after allowing it to come to rest.

5. Give a full explanation of the action of the barodeik. Why should the flask and plate have equal surfaces exposed to the air?

5. HYDROSTATIC BALANCE.

Determination of mass, volume, and density of billiard ball. Use the same balance, weights, and ball as in (1). The resting-point with pans unloaded should be determined

anew each time the balance is used. The sensitiveness need not be re-determined unless the load is quite different.

Put the arch over the left pan, and on it a beaker of water. Suspend the ball in its wire cage from the hook above the pan so that the cage is entirely immersed, and only the fine suspending wire cuts the surface of the water.

Take the temperature of the water before and after the weighing, and consider the mean of the two to be the temperature of both water and ball during the experiment.

(*a.*) Weigh as in (1), and read the barodeik.

(*b.*) Remove the ball, fill up the beaker until the suspending wire of the cage is immersed to the same point as before, and weigh the cage.

(*c.*) Calculate the volume of the ball, assuming volume of 1 gram water = one cu. cm. as an approximate value to be used in the subsequent work.

(*d.*) Calculate the following:

Weight of air displaced by the ball when weighed in (1).

Weight of air displaced by the weights used, assuming their density to be 8.4.

Weight of the ball in vacuo.

Mass of the ball.

(*e.*) Calculate the weight of air displaced by the weights representing the weight of the ball in water in (*a*) and (*b*). From this find what the ball would have weighed in water, if the weighing had been done in vacuo.

(*f.*) Find the weight in vacuo of the water displaced by the ball, and from table 23, calculate the exact volume of the ball. From this volume and the mass, calculate the density of the ball at the temperature of the determination.

6. THERMOMETER CALIBRATION—ABSOLUTE.

Calibration of a 100° thermometer, reading to 1°, which is to be used in subsequent work.

(*a.*) Set a wire-gauze cone into the mouth of a beaker, and fill it with crushed ice. Put the thermometer bulb into the middle of the ice, and let it remain for a few minutes after the reading has become apparently constant.

Record the reading (to 0°.1) and the difference between it and 0° with the proper sign as the correction to the reading at 0°.

To avoid parallax in the readings, always turn the stem so that the reflected images of the divisions in the mercury-thread can be seen, apparently as prolongations of the divisions themselves.

(*b.*) See that the steam-heater contains a sufficient supply of water. Hang the thermometer in the central vertical tube, with the 100° mark just above the cork, arranging the tubes so that the steam will pass up the central tube, down the space between the tubes, and out at the bottom of the outer tube. Thus the thermometer stem is surrounded by steam, and this again by a jacket of steam.

After steam has issued for a few minutes, adjust the lamp so as to give a very feeble current. Why is this necessary?

Record the reading as before, when it has become steady. Read the barometer, and find corresponding temperature of steam from table. Record the difference between this and the observed reading, with the proper sign, as the correction at 100°.

(*c.*) Let the thermometer cool slowly to about the temperature of the room, then repeat (*a*). If the result differs from that previously obtained, ask for advice.

(*d.*) Ask for assistance in breaking off a thread of mercury about 50° in length.

1. Set the lower end at the 0° mark and read the upper end.

Set the upper end at the 100° mark and read the lower end.

2. Repeat with a thread slightly longer or shorter, according as the first was too short or too long.

3. Calculate for each case what the readings would have been if the ends of the thread had been set at the true 0° and 100° marks.

4. The mean of the four readings in (3) gives the middle point of the thermometer, or the true 50° point. From this find the correction at 50°.

(*e.*) Break off a thread 25° in length, and using the 0° and 50° marks as starting-points, find as in (*d*) the first quarter-point, or true 25° point, and the corresponding correction.

(*f.*) With the 50° and 100° marks as starting-points, find the third quarter-point, or true 75° point, and the correction.

(*g.*) Plot on cross-section paper the divisions on the thermometer as abscissæ, and the corrections on a much larger scale as ordinates. Draw as smooth a curve as possible through the plotted points. This gives a calibration-curve for the instrument.

7. THERMOMETER CALIBRATION—COMPARATIVE.

Calibration of a 50° thermometer reading to 0°.1, by comparison with a standard. This standard is a thermometer like the one to be calibrated, but which has been carefully compared with a reliable standard. It should always be returned to the desk after using.

Tie your thermometer to the standard with soft cotton twine, winding it between the stems so as to separate them slightly. Put the bulbs nearly opposite each other; and see that corresponding divisions are as nearly opposite as is consistent with this condition. Suspend the two securely with the bulbs in the middle of a kettle of water, and steady the stems by catching them loosely, without pressure, in a clamp. The thermometers are to be read by a paper-tube telescope, which slides easily on the vertical rod of an iron stand. This should be set with its object-glass at a distance of 40–50 cm.

from the thermometers, which should be perpendicular to its axis. When taking a reading, always set the telescope so that the top of the mercury column appears in the middle of the field of view, not near its upper or lower edge, in order to avoid parallax.

(*a.*) Take a careful series of readings to 0°.01, at intervals of 2° or 3°, from about 12° to 45°. Keep the water well stirred, and keep the temperature fairly constant for a few minutes before each reading. A good plan is to take a preliminary reading of each thermometer, in order to see about where the reading is going to come. The two exact readings can then be made so quickly as to be practically simultaneous.

Read again in a few seconds, taking the thermometers in reverse order. Repeat if necessary until the differences obtained from two such readings agree fairly well.

(*b.*) Let the observers change places, and take a similar descending series, cooling the water by dipping out hot and adding cold.

(*c.*) Ask to see the calibration curve of the standard used, and from it construct a table of corrections to your thermometer at the temperatures used.

(*d.*) Plot a calibration curve as in (5).

CALORIMETRY—GENERAL.

The calorimeter apparatus used consists of a light copper cup, the calorimeter cup proper, and a brass water-jacket, which is wrapped with felt and closed with a wooden cover. The cup rests on three corks in the central space of the jacket, and is thus surrounded by a jacket of air, except for the cork supports and the wooden cover, both poor conductors. A central opening in the cover, above the cup, is closed by a cork through which the thermometer passes.

Two stirrers, one for the cup and one for the jacket, are attached to a common rod which is moved vertically by means of a lever attached to a wooden stand on which the apparatus is placed.

Use the thermometer which was calibrated in (7), and read it with a telescope to 0°.01, as was done there. This will be called the "first thermometer." A second thermometer will be furnished when necessary, to take the temperature of a substance which is to be put into the calorimeter. When this is done, the second thermometer should be compared with the first in a water-bath at nearly the same temperature, in order to find the correction to be applied to its reading. Substances to be poured into the calorimeter should be within 1° or 2° of the temperature of the room, in order to guard against change of temperature in pouring.

Before putting either thermometer into a hot liquid, always test with a 100° thermometer to make sure that its temperature is under 50°.

The difference in temperature between cup and jacket is usually made as small as possible by adjusting the temperature of the water in the jacket to that necessary for the cup. The rate of change of temperature of the cup, due to radiation across the air-space which is caused by this difference, is thus made as small as possible, and being fairly constant, can be observed and allowed for.

All weighings should be made accurate to about 0.2 per cent, which can be done on trip scales except where otherwise specified.

8. WATER EQUIVALENT OF CALORIMETER.

Determination of the thermal capacity of the cup, with its stirrer and the portion of the thermometer which is immersed in water when the cup is nearly filled, as in ordinary use.

This being the number of grams of water to which the apparatus is thermally equivalent, is called its "water equivalent."

(*a.*) Weigh a beaker containing enough water to half fill the cup, and set it on the stand beside the calorimeter so that the second thermometer can be hung with its bulb in the water. Adjust the thermometers so that either can be read easily by merely turning the telescope, without altering its focus.

Weigh the cup, fill ¾ full of water at about 40°, and weigh again. Fill the jacket with water at the same or a somewhat higher temperature, pouring it in through a small funnel. Be careful always to avoid getting water into the air-space in the jacket, and also to avoid wetting the felt wrapping.

(*b.*) While one observer keeps the stirrers in gentle but continuous motion (one stroke in 4 or 5 seconds is usually sufficient) let the other read the thermometer, at intervals of one minute, for 4 or 5 minutes. By this time the difference between successive readings should be quite constant. At some time during the series, stir the water in the beaker with the thermometer bulb, and read its temperature between two readings of the first thermometer. Now raise the cork from the calorimeter cover, and pour in enough water from the beaker to nearly fill the cup. This should be done by the one who has been handling the stirrer, and so timed that the mixture is made at a half minute, between two readings. Resume the stirring at once, and continue the thermometer readings at each minute for a few minutes as before.

(*c.*) From the average rate of change of temperature of the cup before and after making the mixture, calculate the temperature of the cup at the moment before the mixture was made, and at the moment after, assuming that the change in temperature due to the mixture was instantaneous.

Reweigh the beaker to find weight of cold water used.

(*d.*) Denoting by x, the thermal capacity of the apparatus,

which is the quantity to be determined, construct an equation involving the following quantities:—

1. Quantity of heat lost by the hot water in the cup.
2. Quantity of heat lost by cup, stirrer, and thermometer.
3. Quantity of heat gained by cold water poured in.

From this equation find x. Use corrected temperatures in calculating.

(*e.*) Repeat with initial temperature a few degrees lower, and take the mean of the two results.

(*f.*) As a check on the preceding result, calculate the thermal capacity of the cup and stirrer from their weights and the specific heats of copper and brass, which may be found in the tables. To this must be added the thermal capacity of the immersed portion of the thermometer, which may be experimentally determined with sufficient accuracy as follows:

Set up the calorimeter, leaving out the cork, with water at the room temperature in both cup and jacket, having first weighed the cup and contained water. Record the temperature when it has become steady, then take out the thermometer and immerse it, to the same depth as is usual in the cup, in water at about 45°. After a few minutes, read the temperature to 0°.1, then as quickly as possible take out the thermometer and put it into the usual position in the calorimeter, shaking off superfluous water on the way. Stir until the temperature becomes steady and record the reading. Then calculate the thermal capacity of the thermometer according to the general method used in (*d*).

(*g.*) If this result differs from the final result in (*e*) by more than one unit, ask for advice. If it does not, use the mean of the two as the water equivalent of the apparatus in future work.

The different sets of apparatus are nearly enough of the same dimensions so that this result may be used with any of them.

9. SPECIFIC HEAT OF LEAD SHOT.

Set up the apparatus, take observations and calculate results as in Exp. 8, (*a*), (*b*), (*c*) and (*d*), with the following modifications: —

(*a.*) For the beaker of water, substitute a copper cup containing about 700 grams of dry shot. Fill the calorimeter cup only about ⅔ with water, to avoid risk of running it over when the shot is poured in.

(*b.*) When the shot is poured in, the temperature will not be well equalized by the ordinary stirring, as the stirrer will not penetrate the mass of shot. It is necessary to unhook the thermometer from its support and stir the shot very carefully with its bulb for about one minute. Then replace the cork, hang up the thermometer and resume the readings, one of which has thus been omitted. From this point the ordinary stirring is sufficient.

(*c.*) In writing the equation, x should now denote the specific heat of the shot, and the thermal capacity of the apparatus is known.

(*d.*) Repeat with a fresh portion of shot, and a higher initial temperature of about 46°.

Wash the shot well after use, and spread it in a thin layer on a cloth to dry.

10. HEAT OF SOLUTION. AMMONIUM NITRATE.

The quantity of heat absorbed in the solution of one gram of a substance is called its heat of solution. If heat is given out in the solution, the quantity is considered negative.

If the temperature of the salt after solution be different from that at which it was poured into the water, it will be necessary to consider its specific heat also. According to the following method the heat of solution and the specific heat

are both determined, although the former is the main object of the experiment.

On one of the Becker balances weigh out two portions of the salt, each of 10 grams, to 0.01 gram. This can be conveniently done by putting two equal pieces of paper in the two pans, and pouring the salt on one of them. Never put the salt directly into the pan. Put each portion, after weighing, into a smallest-size beaker which is thoroughly dry.

This amount of salt, when dissolved in about 200 grams of water, will lower its temperature a little over 3°. It is best to have the cup about 3° degrees warmer than the jacket, because the larger part of the salt dissolves in a few seconds, so that the cooling during this time is small; and the temperature being then reduced to about that of the jacket, there is no cooling during the longer time required for the complete solution of the salt.

(*a.*) With the jacket at the room temperature and the cup about 3° higher, proceed as in (8). In removing the second thermometer from the beaker of salt, after taking its temperature, see that no salt is removed. After pouring in the salt, stir rather vigorously to hasten the solution, and record the temperature when it has become steady.

(*b.*) Make a similar trial with the second portion of salt, having the jacket at 40° or higher. Make sure that there is the proper difference of temperature between the cup and the jacket before beginning the observations.

(*c.*) Calling the specific heat of the salt x and its heat of solution y, write the proper equation for each case, and solve the two equations for x and y.

CAUTION.—Do not leave the solution standing in the copper cup. Wash it out as soon as possible.

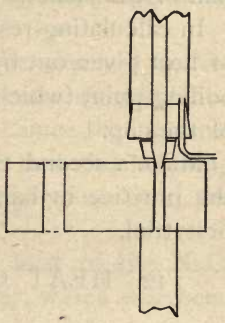
11. LATENT HEAT OF VAPORIZATION.

Examine the construction of the steam-trap, and see that

when held vertically, with the exit tube down, it will catch and discharge through the side vent all water which is condensed on the way from the boiler, and permit only dry steam to issue from the exit. Fill the boiler nearly full of water, heat it to boiling, then remove the lamp until ready to use the steam.

The steam will be condensed in a copper tube, closed at the bottom, which projects downward from the lower surface of the cork into the calorimeter cup. This tube, closed with a dry cork and well dried on the outside, is to be weighed, before and after using, on one of the delicate balances. These balances must be handled with especial care. See that the pans are protected by sheets of filter-paper. Adjust the weights to the nearest centigram, then use the rider to obtain the nearest milligram. Never touch weights or rider without first arresting the pans.

The cut is a section through the cork, showing the proper arrangement of the trap and tube when in operation. See cut. The cup must be filled until the water rises almost, but not quite, to the lower surface of the cork, so that the copper tube may be immersed as deeply as possible. The proper amount of water should be determined by a preliminary trial.



Lay a small piece of blotting-paper over the hole in the cork, and punch a corresponding hole through the paper, using the exit tube as a punch. When steam is issuing from the tube, an occasional drop of water forms at the mouth, which will be absorbed by the paper. The object of these precautions is to make sure that the water which is collected and weighed in the tube is simply that which, in condensing on the walls of the tube, gives up its heat of vaporization to the water in the cup.

Put in the cup the proper amount of water at a temperature about 3° below that of the jacket, which should be at the room temperature. Set the lamp under the boiler, and adjust its height so that when steam is issuing freely the water stands at about 25 cm. in the manometer tube. This gives a vigorous current of steam, without raising the boiling point too much. The stirring of the jacket may be dispensed with, and the cup stirred directly by hand. After reading temperatures for a few minutes, put the steam-trap in position, with the side vent pointing away from the thermometer, and press down so tightly that no steam escapes around the cork. Stir gently until the temperature has risen about 6°, then remove the trap, continue stirring, and record the highest temperature. Corrections for cooling are practically unnecessary, since the range of temperature is distributed equally above and below that of the jacket.

In calculating results, remember to account for the quantity of heat given out by the condensed steam in cooling from the boiling-point (which may be taken as 100°) to the temperature of the cup.

Make a second trial, which should give a good result, with the practice in handling the apparatus acquired during the first trial.

12. HEAT OF CHEMICAL COMBINATION.

Determination of the heat generated by the combination of NaOH with HCl to form NaCl.

A 0.5 normal solution of each of the above compounds is furnished. By a normal solution is meant one which, in 1,000 grams of the solution, contains a weight of the element which is to enter into the new combination equal in grams to its atomic weight. Thus the normal solution of NaOH is a solution which contains, in 1,000 grams, 40 grams (23+16+1) of NaOH, or 23 grams of Na. The 0.5 normal solutions used contain one-half of these proportions.

It is evident that if equal weights of these solutions be mixed, the reaction will be just completed, and the result will be a neutral solution of NaCl. The solutions are to be mixed in the calorimeter cup at as nearly as possible the same temperature, and the resulting rise of temperature noted. The alkali should be placed in the cup, and the acid added to it. The acid being immediately neutralized, will then have no action on the metal of the cup.

Weigh out 100 grams of the NaOH solution in the cup, and the same amount of the HCl solution in the beaker. The latter should be weighed out roughly at first, poured back into the bottle, then the wet beaker counterpoised and the amount weighed accurately. This will then be quite accurately the weight which is afterward poured into the calorimeter. A small error is introduced by taking the second thermometer out of the beaker after reading its temperature, but this may be neglected.

If care has been taken not to handle the cup and beaker any more than necessary, the two temperatures should be very nearly the same when ready for use. Since the amounts used are equal, it may be safely assumed that the resulting solution of NaCl has risen to the final temperature from the mean of the two initial temperatures.

A direct determination of the specific heat of the NaCl solution is impracticable. The value 0.987, which has been calculated by interpolation from tabulated results, may be used for this case.

Make two trials, and calculate for each the number of heat units which would have been evolved had normal solutions been used.

13. COEFFICIENT OF EXPANSION OF A LIQUID.

The method consists in determining the weights of alcohol filling a specific gravity bottle at several different temperatures,

and from these data calculating the coefficient of expansion. Four determinations should be made, at intervals of about 8°, beginning with the room temperature.

(*a.*) Fill the bottle with alcohol and set it on a platform in a kettle of water, so that the water comes as high as the alcohol in the bottle. See that the stopper is set in very lightly. Hang your 50° calibrated thermometer in the bath beside the bottle, and keep the bath well stirred for about 5 minutes. The temperature of the bath should remain constant within 0°.1 during this time, and at the end of it the alcohol will have the same temperature within 0°.1.

Set the stopper in tightly, using no more pressure than necessary, take the bottle out of the bath, wipe dry and weigh to 0.001 gram on one of the delicate balances.

(*b.*) Repeat with the bath at about each of the higher temperatures selected, holding the temperature steady for 10 minutes by holding the lamp under the kettle for a few seconds occasionally. Before putting the bottle in the bath, loosen the stopper to allow the excess of alcohol to escape, and try it occasionally to see that it remains loose during the warming. Careful trial has shown that, after this treatment, the temperature of the alcohol at the center of the bottle, as shown by the thermometer in the stopper, is about 0.°1 lower than that of the bath, and therefore the average temperature of the alcohol is the same as that of the bath to within 0°.1.

(*c.*) Empty the alcohol into the bottle from which it was taken, dry the bottle with the jet-pump, and weigh. (Ask for directions as to the use of the jet-pump.)

(*d.*) Find the weight of alcohol filling the bottle at each temperature. Plot the results, with the corrected temperatures, starting from 0°, as abscissæ, and changes in weights as ordinates. Assuming that the expansion is uniform, draw the straight line which best represents the plotted points, and from it find the weight filling the bottle at 0°.

(*e.*) From the weights filling the bottle at 0° and at 40°, calculate the relative volume of a given weight of alcohol at 40°, referred to its volume at 0°. From this calculate the coefficient of cubical expansion of the alcohol for the given range of temperature. (Coefficient of expansion is expansion of 1 cu. cm. from 0° to 1°.)

(*f.*) Note that what you have obtained is not the absolute coefficient for alcohol, since the bottle also expands. Find from the tables the coefficient of cubical expansion of glass, and by applying it to the above result, find the absolute coefficient for the alcohol. Remember that the expansion of the interior of a glass bottle is equal to the expansion of the same volume of solid glass.

14. VOLUMENOMETER.

Density of NaCl Crystals.

The apparatus is designed to measure the volume V of air inclosed above a certain mark on the glass tube. The given volume is inclosed over mercury, and its pressure p measured by the manometer. By raising or lowering the manometer tube, the volume of the inclosed air is changed by an amount v_1, which can be measured, and the corresponding pressure p_1 is read. By Boyle's law, $pv = \text{const.}$ Hence $pV = p_1 V_1$, where $V_1 = V + v_1$, from which V, the original volume, is determined. The temperature is assumed to remain constant.

CAUTION.—Put no dirty mercury into the instrument, and see that there is a mercury-tight tray on the floor underneath it.

(*a.*) Having the brass tube unscrewed from the upper end of the fixed glass tube, so that the latter is open to the air, set the movable tube, pouring in more mercury if necessary,

so that the top of the column in the fixed tube is at the middle mark. See that the brass tube is empty except for a plug of cotton. Clean off the old grease from its end, and from the shoulder on the brass cap, smear a little fresh grease evenly on the screw-threads of the cap, and screw on the tube, making sure that it fits tightly against the shoulder.

Readjust the open tube so that the edge of the meniscus in the closed tube is again at the mark. The volume now inclosed above the mercury is the volume V to be determined.

Read the position of the top of each column on the meter rod by means of a straight edge laid across its face, and from the difference in level and the barometer height, find the pressure p on the inclosed air.

(*b.*) Raise the open tube, pouring in more mercury if necessary, until the mercury rises to the upper mark in the closed tube. Let stand a few minutes to allow the inclosed air to return to the temperature of the surrounding air, then read both columns. Let stand five minutes, and read again. Any difference is probably due to leakage in the screw-joint, which must be made tight.

Repeat the setting three or four times, bringing the column in the closed tube to the mark and reading the open tube each time.

From the heights of the two columns, find the pressure p_1.

(*c.*) Lower the open tube, catching the overflow in a beaker, until the column in the closed tube sinks to the lower mark. Read both columns as before, and find the pressure p_2 for this case.

(*d.*) Bring the inclosed air back to nearly atmospheric pressure, and unscrew the brass tube. Take out the cotton plug from the brass tube, fill it nearly full of clean NaCl crystals, and replace the plug so that they will not fall out. Repeat (a), (b), and (c), the volume V now being less than before by the volume of the crystals.

(*e.*) A separate tube is furnished which contains the volumes v_1 and v_2 between marks corresponding to those on the volumenometer. To find these volumes, fill the tube to the marks with mercury, from a separate supply, pour into a weighed beaker and weigh, using Becker balance. The volume of one gram of mercury at the room temperature may be found in the tables.

(*f.*) Calculate the value of V for each case, and so find the volume of the crystals used.

Weigh the crystals, and calculate their density.

15, 16, 17, 18. MEASUREMENTS OF CHANGE OF VOLUME WITH TEMPERATURE.

The apparatus used is practically a thermometer with a large bulb, open at the end. This opening can be closed by a stopper consisting of a flat surface of rubber which is pressed against it by springs. The constants of the instrument are determined in the first two experiments, for use in the two succeeding.

The instrument furnished to each pair of students will be used by them only, until the four experiments are completed.

15. CALIBRATION OF THE TUBE.

Always handle mercury over a mercury-tight tray.

(*a.*) The cm. divisions nearest the ends of the scale will be considered as the ends of the scale to be used, corresponding to the 0° and 100° marks on the ordinary thermometer scale. Pour a little mercury into the bulb and run it into the tube, so as to secure a continuous thread as long as the scale. Adjust by pouring out a drop at a time from the end of the tube. Read the length of the column, find its weight, to 1 cg., and from this find the volume of the tube between the two ends of the scale.

(*b.*) Find the middle and quarter points by the method used in 6, and also find the eighth points, midway between the quarter points. The bore of the tube is apt to vary considerably in different parts, so that the quarter points will not give a sufficiently good calibration.

(*c.*) On a sheet of co-ordinate paper, lay off the divisions of the scale as abscissæ, and at each of the points on the scale found above, including the upper end of the scale, erect an ordinate which will represent the volume of the tube from the zero up to that point. A curve through these points will then give the volume of the tube between any two points on the scale. Such a curve can be best drawn with a flexible ruler, such as a strip of spring brass on edge, held at the ends so as to pass through all the points.

16. EXPANSION OF THE THERMOMETER.

(*a.*) Fill the thermometer with clean mercury, getting the right quantity by trial so that the top of the column will rise in the tube to the lower part of the scale when the stopper is set in place so as to inclose no air-bubbles.

Always steady the bulb with one hand when handling the stopper, as a slight twist of the bulb may break the tube.

(*b.*) Immerse the bulb in a water-bath so that the tube will be vertical, and suspend your 100° calibrated thermometer beside it. Read the height of the column in the tube at intervals of about 10° up to 60°, holding the temperature of the bath steady at each chosen point for a few minutes after the reading of the expansion thermometer has become steady, and reading the temperature to 0°.1. Then cool the bath, and take a similar set of readings at temperatures intermediate between those previously used.

If there is time, heat the bath again, taking a second series of readings.

Find the weight of mercury used, by carefully pouring it out into a weighed beaker, and from this find its volume. Use trip scales.

(*c.*) Plot the results, using corrected temperatures starting from 0° as abscissæ, and corresponding volumes of the tube, from the volume-curve, as ordinates. Draw the straight line which best represents the plotted points. Through the point where this line intersects the ordinate at 0°, draw an axis parallel to the axis of abscissæ. The apparent expansion of the mercury in the thermometer, from 0° to any given temperature, will then be represented by the corresponding ordinate measured from this axis to the plotted line.

(*d.*) At the highest temperature used, erect an ordinate from this axis which will represent the absolute expansion of the mercury used, from 0° to this temperature, and draw a line from this point to the 0° point. The difference between corresponding ordinates to the two lines gives the expansion of the apparatus. Construct a third plot which will represent this expansion measured from a horizontal axis.

(*e.*) Assuming that the apparatus is made entirely of glass, calculate the coefficient of expansion of the glass.

17. EXPANSION OF COTTON-SEED OIL.

Fill the instrument with oil, in the same way that it was filled with mercury in the last experiment. There will be less trouble with air-bubbles if the oil is poured into the bulb slowly, in a steady stream.

(*a.*) Set the thermometer in a water-bath as before, and take a similar set of ascending and descending readings. The oil is such a poor conductor that it will be necessary to keep the temperature of the bath constant at each reading for a much longer time than with the mercury.

(*b.*) Plot the observations as in 16, (*c*). To correct for the

expansion of the apparatus, measure from this line at some convenient temperature an ordinate, in the proper direction, to represent the expansion of the thermometer from 0° to that temperature, taken from the final plot in 16. Then a line drawn through this point and the point where the first line intersects the ordinate of 0° will represent the true expansion of the oil.

(*c.*) Calculate the coefficient of expansion of the oil. The volume at 0° of the oil used can easily be calculated, but if the result be found in terms of the volume at the lowest temperature used, it will be nearly enough the same.

Leave the oil in the thermometer for the next experiment.

18. EXPANSION OF NaCl CRYSTALS.

The bulb is now to be filled with a weighed amount of NaCl crystals, leaving the spaces between them filled with the oil used in the last experiment.

Set the thermometer, still containing the oil, in the bath with the bulb partly immersed, its axis being vertical, and heat to 70°.

Pick out and weigh enough clean NaCl crystals to more than fill the tube. Remove the stopper from the bulb and drop in the crystals one at a time. The heat, and gentle stirring around with a bit of wire, will set free the air-bubbles which at first are caught by the rough surfaces. After getting in the proper amount of crystals, fill up with oil and take a set of readings as in 17. Weigh the remaining crystals, and calculate the volume used from the density found in 14.

Plot the observations, and correct the line obtained for the expansion of the thermometer, and of the volume of oil used.

From the resulting line representing the true expansion of the crystals, calculate their coefficient of expansion.

ELECTRICITY—GENERAL DIRECTIONS.

To set up a Daniell cell: The zinc plate is left standing in water in the outer cup, and the inner porous cup, filled with $CuSO_4$ solution and containing the copper plate, is kept soaking in a jar of the solution. Clean off any scale from the surface of the zinc by rubbing it with a rag or the fingers, under the tap, and put it in place. Rinse off the outside of a porous cup, which is filled to within 3 or 4 cm. of the top with $CuSO_4$ solution, and put it inside the zinc. Fill the space around it with dilute H_2SO_4 from one of the labeled bottles.

When you have finished using the cell, put it away as it was found, returning the acid to the bottle.

If gas is given off when the acid is first poured in, the zinc needs amalgamating. Ask for directions.

When these precautions are observed, the electromotive force and resistance of the cell will be very nearly the same at one time as at another. The resistance may change slightly for a few minutes on first setting up.

In setting up a circuit of any kind, clean all the connections, including those at the battery terminals, with knife, sandpaper, or file. Never make connections by twisting the ends of wires together, as the resistance of such a connection is very variable. Always use binding screws, and make sure that the ends of the wire are firmly held by the screws.

If at any time the current seems to be variable, or too weak, examine the connections first, as they are very likely to be the seat of the trouble.

Do not move tangent galvanometers without first asking permission; and handle them carefully, to avoid breaking the silk fiber suspensions. If the pointer does not swing freely after adjusting the leveling screws, ask for assistance.

In using galvanometers with pivot suspension, tap the

instrument with some soft object before taking a reading. Raise the needle from the pivot before leaving the instrument.

Binding screws and connecting wires will be found at the northwest corner of the room; return them to their places after use.

In making connections, do not use wires which are longer than necessary, and make a practice of arranging wires so that currents in opposite directions shall be as near each other as possible, in order to minimize effect on galvanometer needle. Use wires of small diameter, except in special cases where it is desirable to make the resistance of connections as small as possible.

In using resistance boxes, take care to protect the plugs, and the tapered holes into which they fit, from bruises and dirt. Never interchange plugs between boxes without permission. Keep boxes covered when not in use.

19, 20, 21. TANGENT GALVANOMETER.

General Theory.—A unit magnetic pole is defined as one which, when placed in air at a distance of 1 cm. from a pole of equal strength, will exert upon it a force of 1 dyne.

A unit current is defined as one which, flowing in a wire 1 cm. long, bent into an arc of 1 cm. radius, will act on a unit magnetic pole at the center of the arc with a force of 1 dyne.

We shall speak of the field at the center of the coil, due to the current flowing in it, as the force in dynes exerted by the current on a unit pole at the center of the coil; let this be denoted by F.

For a unit current, flowing in a circular coil of 1 turn, radius 1 cm., $F=2\pi$; for n turns, $F=2\pi n$. If the radius of the coil be r, $F=2\pi n/r$; since the field due to a given length of wire varies as $1/r^2$, but the length of wire in the coil is r

times as great. This value of F, namely the field produced at the center of the coil by a unit current flowing in the coil, is called the constant K of the galvanometer.

H denotes the horizontal component of the earth's magnetic field at the center of the coil. Then if the coil be set with its plane vertical and in the magnetic meridian, the two fields of force denoted by F and H will act in directions at right angles to each other, upon each pole of the needle. Assuming the needle to be so short that the field at each pole is the same as at the center of the coil, if the current c cause the needle to deflect through an angle a from its zero position, show that in general $\tan a = F/H = cK/H$. From this $c = (H/K) \tan a$.

c is here expressed in c. g. s. units. The commercial unit, the ampere, is 0.1 of the c. g. s. unit. Hence if c be expressed in amperes, $c = (10H/K) \tan a$. $10H/K$ is called the reduction factor R of the galvanometer.

19. TEST OF TANGENT LAW.

(*a*.) Set the galvanometer with its plane in the magnetic meridian. With the instruments used, this is done by bringing the ends of the pointer to 0° and 180°. Set up a Daniell cell, and connect it in series with the galvanometer and resistance box. On the galvanometer set the plug of the small switch-board in the hole marked 50; the current then flows through a coil of 50 turns. Take out plugs from the box until the deflection is about 50°.

Determine the deflection by reading both ends of the pointer, to 0°.1, then reversing the terminals to get a deflection in the opposite direction and reading both ends again. The mean of the four readings is the deflection required. Increase the resistance in the box so as to obtain deflections at intervals of 5° or 6°, down to about 10°.

In what follows, the electromotive force and resistance of the cell are supposed to remain constant throughout the experiment. To test this, repeat the first reading. If it does not agree with the former value, repeat the series in the same order as before to a point where the new values do agree with the old.

(*b.*) Show the truth of the relation expressed on the preceding page, tan $a = F/H$. By combining this with Ohm's law, $E = cr$, where r is the total resistance in the circuit, show that $E/R = r \tan a = r/\text{cotan } a$.

If then you make a plot with resistances as abscissæ and cotangents of corresponding angles of deflection as ordinates, the points obtained should lie on a straight line if the galvanometer obeys the tangent law.

(*c.*) Make such a plot from your observations, using box resistances as abscissæ, and show how to obtain from it the constant resistance in the circuit outside the box. Do this first by reading it directly from the plot, and then, more accurately, by constructing the equation of the line and calculating from it.

What does this resistance include?

The same galvanometer must be used for the next two experiments.

20. REDUCTION FACTOR.

(*a.*) Set up your galvanometer with its needle as nearly as possible over one of the numbered brass nails on the tables. Straighten out two of the copper wire spirals from the voltameter cells, clean and smooth them well with fine emery paper, and re-wind on a brass rod provided for the purpose. Do not touch the wire with the fingers except at the ends, after cleaning; catch one end through the small hole in the brass rod, and having the other end secured,

stretch the wire while winding, so as to get a smooth spiral. If the surface of the wire flakes off in cleaning, ask for new wire. Clean the copper plates of the voltameters, replace them and the spirals, and fill the cells with fresh electrolyte solution from the bottle.

Connect the two voltameters in series with a Daniell cell and the 5-turn coil of the galvanometer, in such a way that copper will be deposited by the current on the spirals. Insert German silver wire if necessary to reduce the deflection to about 25°.

(*b.*) When the deflection remains practically constant for several minutes, lift the spirals out of the solution and see if they are uniformly covered with a bright and clean deposit. If so, plunge them at once in a beaker of clean water, then wash thoroughly under the tap and dry by gentle heat, no greater than may be easily borne by the hand.

Weigh the spirals separately to 1 mg. on the delicate balance.

The battery should be allowed to send a current through some convenient resistance while not in use.

(*c.*) Replace the spirals in the voltameters, put them in circuit as before, and let the current run for 50 minutes 50 seconds. Read the deflection at each minute, reversing its direction at about the middle of the period. Repeat the washing, drying, and weighing. The gain in weight should be the same for the two spirals. If it is nearly the same, take the mean.

(*d.*) Remembering that the weight of copper in grams deposited by the current in the given time is numerically equal to the current strength in amperes, calculate the reduction factor for the coil used. If the deflection has not remained constant, the mean of the tangents of the observed angles should be used in the calculation. However, if the variation has not been large, the tangent of the mean angle may be used instead.

Do not replace the used electrolyte solution in the bottle, but pour it in the jar containing porous cups.

21. CONSTANT.

(*a.*) To calculate the constants of the 1-turn, 5-turn and 50-turn coils, from their measured dimensions.

Measure with a beam-compass the diameter of the ledge on the face of the ring, which is the same as the diameter of the bottom of the groove, or the inner diameter of the coil. Also measure the outer diameter of the wire coil. In each case take several measurements along different diameters.

The first layer, in the bottom of the groove, consists of six turns of No. 14 wire, so connected that the current flows through all six in parallel, thus making one effective turn. This is the 1-turn coil. The next layer, of No. 16 wire, consists of two wires in parallel wound four times around, thus making four turns. These eight wires just fill the width of the groove, as do the six wires of the first layer. The four turns and the one may be connected in series, making the 5-turn coil. Outside of this are 45 turns of No. 22 wire, which may be connected in series with the five turns, to make the 50-turn coil.

The coils of galvanometers 1 and 2 are not wound according to the plan here described. If they are used, ask for the plan.

Samples of No. 14 and No. 16 wire are furnished. From the measured diameters of these, and the inner and outer diameters of the whole coil, find the mean diameter of each coil. Calculate the constant for each coil.

From the definition of the constant it is evident that the constant for two coils in series is the sum of the two constants taken separately. Find thus the required constants for the 1-turn, 5-turn and 50-turn coils.

(*b.*) From the constants, and the reduction factor for the 5-turn coil, calculate the reduction factors for the 1-turn and 50-turn coils. From the plot of Exp. 19, take a pair of values of r and cotan a, and find the electromotive force of the cell used from these and the proper reduction factor.

(*c.*) Find the value of H at the point where the needle of the galvanometer was situated in Exp. 20. Locate this point by measuring, by means of two meter rods placed end to end in succession, the distance (x) from the west wall of the laboratory, (y) from the south wall, and (z) from the floor. This gives the three co-ordinates of the point, referred to rectangular axes with origin at the southwest corner of the floor.

22. VARIOMETER.

From the value of H found in the last experiment, to determine its value at another point in the room. The point to be used is No. 10, in the northeast part of the room. The instrument is a tangent galvanometer, adapted to the purpose by attaching to the top of the coil a carriage rotating in a horizontal plane for the control magnet. As the strength of this magnet is supposed to remain constant throughout the experiment, it must not be jarred, nor brought into contact with iron.

(*a.*) Release the galvanometer needle by raising the pin at one side of the scale, and, having the control magnet removed a short distance and stood up vertically to neutralize its magnetic effect, turn the coil and scale until the pointer stands nearly at 0°. Read both ends accurately. See that there are no masses of iron on the table, or on the persons of the observers, which might affect the readings. Now place the control magnet in its carriage, which should be placed approximately at right angles to the plane of the coil, and

clamped just firmly enough so that it will rotate with some difficulty.

(*b.*) Read both ends of the pointer. Lift the control magnet from the carriage, and after reversing its direction, replace it without moving the carriage. Read the pointer as before. Calculate the true deflection in each direction from the zero found in (*a*). If the two deflections agree, show that the axis of the control magnet must be at right angles to the earth's lines of force. If they do not agree, see which way to rotate the carriage in order to make the difference less, and by repeated trials reduce it to a small quantity.

How could this method be used to set the plane of the coil of a tangent galvanometer in the magnetic meridian, by means of the current in its coil?

(*c.*) Let each observer read several sets of deflections in both directions. Take the mean of the series as the true deflection.

(*d.*) Leaving the carriage clamped in position, raise the needle from the pivot, and set the instrument with the needle as nearly as possible at the point where the value of H is known. Adjust the pointer to 0°, and take a series of readings of deflections as before. If a galvanometer is in use near by, determine whether it will affect your work by taking a careful reading when a current is flowing in the coil, and again when it is not. If the effect is appreciable, try to obtain your readings when no current is flowing.

(*e.*) Again set the instrument in its first position, and repeat the first set of readings. If the result does not agree with that previously obtained, it is evidence that the strength of the control magnet has probably changed. The mean of the two results should be taken as corresponding most nearly to the condition of things at the time when the readings in (*c*) were taken.

(*f.*) Noting the similarity between the field produced at the

center of the coil by the control magnet and that which would be produced there by a current in the coil, show how to calculate the ratio of the values of H at the two points, and from this its absolute value at the new point. Find the co-ordinates of this point as before.

23. VOLTMETER CALIBRATION.

Any galvanometer may be used as a voltmeter if its resistance be sufficiently high. A mirror galvanometer is here used, its deflections being measured by means of a telescope and scale.

The galvanometer used has not the necessary high resistance. Its coils are to be connected in series with a resistance coil, and the galvanometer and resistance coil taken together then constitute the voltmeter.

The method used for the calibration depends upon the fact that if a constant current be maintained through a circuit of given resistance, the E. M. F. between any two points on that circuit varies as the resistance included between them. The voltmeter is so arranged as to read the E. M. F. between various pairs of points on such a circuit, which consists of a wire of uniform resistance.

(*a.*) On the rheostat provided, each of the six loops and the stretched wire are of the same length, and may for the present be assumed to have the same resistance. This equality will be tested afterward. Set up a Daniell cell at once, and connect it to the terminals A and B of the rheostat, in order that the current may become steady by the time the readings are to be made.

Notice that if all three of the plugs provided are in place, in any three holes, the current from the cell will flow through four meters of wire. By changing the plugs from one end of the board to the other, the straight meter on which the sliding

contact works may be made the first, second, third or fourth of the four meters; so that the sliding contact may be made to move from one end to the other of the four meters through which the current is flowing. The circuit as now set up will be called the main circuit.

(*b.*) If the galvanometer does not work properly at any time, do not attempt to adjust it, but ask for assistance.

Set the telescope about on the normal to the mirror, which may be easily located by seeing the reflection of your eye in it. Make the distance of the scale from the mirror (measured to the axis of the tube containing it) 150 cm. Point the telescope tube by sighting along it, directly at the mirror. Raise or lower the scale until its image is seen in the mirror on looking along the tube. If this is carefully done, the image of the scale should be distinctly seen in the telescope when it is properly focused. Move the telescope sideways, making the last small adjustment with the slow-motion screw, until the image of the center division of the scale, marked 0 or 20, coincides with the vertical cross-wire in the eye-piece.

For each setting the true deflection is to be obtained by taking the mean of the deflections to right and left on reversing the current.

(*c.*) If the current as it is now flowing in the main circuit causes an appreciable deflection of the galvanometer needle (tested by making and breaking the circuit), try to reduce it by proper arrangement of connecting wires.

See that the inner edges of the slides to which the galvanometer coils are attached are at division 10 on the scale, if the Edelmann galvanometer is used; if the other instrument is used, set the outer edges of the slides at 12.5.

(*d.*) It will be best now to make a sketch on paper of the whole scheme of connections, and ask to have this verified before setting up. For this purpose the four meters of wire in the main circuit may be represented as a single straight

piece, and the galvanometer circuit added according to the following description.

Such a sketch of connections should accompany the notes of each of the following experiments on electricity.

Connect the resistance coil (500 ohms for the Edelmann, 1,000 for the other) in series with the galvanometer coils, to make up the necessary high resistance for the galvanometer circuit. Connect one terminal of this circuit to one terminal of the rheostat, the other to the binding-screw *c*, at the end of the brass rod on which the sliding contact moves. The galvanometer circuit may thus be put in parallel with any desired portion of the main circuit by proper arrangement of plugs.

Include in the galvanometer circuit a mercury-cup commutator, in such a way that tipping it from one side to the other will reverse the direction of the current in the galvanometer circuit, without affecting that in the main circuit. It must evidently be put between the rheostat and the galvanometer. Include in the galvanometer circuit also a key near the telescope, enabling the observer to make and break that circuit at pleasure.

It is evident that in setting up these connections, small wires may be used throughout.

(*e.*) Reckoning from that rheostat terminal to which the galvanometer terminal is attached, arrange the plugs so that the stretched meter shall be the first of the four. Let one observer set the sliding contact at the first marked point, which is 20 cm. from the end, thus putting the galvanometer circuit in parallel with 20 cm. of the main circuit, and let the other read the deflection; then reverse the commutator and read the opposite deflection. Repeat for the other marked points, at 50 and 80 cm. Learn to control the vibrations of the needle, so as to bring it to rest quickly, by proper use of the key.

Change the plugs so as to make the stretched meter suc-

cessively the second, third and fourth of the series, and for each case read the deflections for each of the marked points. Record for each case the total length of wire on the main circuit with which the galvanometer circuit is in parallel, and also the numbers of the loops used in making up each combination for the main circuit.

The observers should change places at about the middle of the series.

(*f*.) If there is time, repeat the series in reverse order, moving the galvanometer terminal which was at one terminal of the rheostat to the other one. The lengths of wire now included between the galvanometer terminals will be measured from the opposite end of the four meters. Use the same combinations as before in making up the main circuit, for convenience.

If the resistance in the galvanometer circuit remain constant, show that the currents indicated by the deflections will be proportional to the E. M. F.'s between its terminals; and that, if the resistance be sufficiently large compared with that of the main circuit, these E. M. F.'s will be proportional to the resistances of those portions of the main circuit included between the terminals.

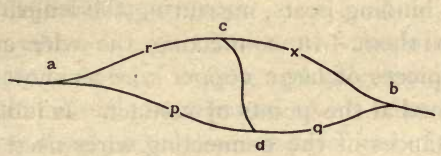
Finally connect the terminals of the galvanometer circuit directly to those of the cell, leaving out the rheostat entirely, and read the deflection. Show that the current here indicated should be proportional to the E. M. F. of the cell, as determined in Exp. 21.

Calculations may be deferred until Exp. 25, and the papers for this exercise and that handed in together.

24. WHEATSTONE BRIDGE.

If a current be sent through two wires in parallel, there will be a certain E. M. F. between the two ends *a* and *b* of this

portion of the circuit. If a point c be chosen on one of the wires, there will be a certain E. M. F. between a and c. A point d can then be found on the other wire, such that the same E. M. F. exists between a and d. It is then evident that if the points c and d be connected by a wire, there will be no E. M. F. between them along this wire, and hence no current will flow in the wire. The point d may then be found by inserting a delicate galvanoscope as part of the circuit cd, and moving d along adb until no current is indicated.



By applying Ohm's law to each of the four portions ac, cb, ad, db, show that when this adjustment has been made $r/x = p/q$, where r denotes the resistance of ac, x that of cb, etc.

In the apparatus used, adb is a uniform stretched wire of German silver 1 meter long, and d is a sliding contact on this wire. x is an unknown resistance to be determined, and r is a known resistance (for this experiment a coil whose resistance in ohms is marked upon it).

It is evident that a constant cell is not required, since the relations obtained above are independent of the current-strength in the main circuit. (They will not be true, however, for rapid variations in that current, since Ohm's law does not hold for such cases.) It is customary to use a Leclanche cell, dry cell, or other inconstant element, and to include in the battery circuit a key which is only depressed while taking an observation, since such cells can not send a strong current for any length of time without injury.

Be careful never to connect such a cell so that it will send a continuous current.

To determine the resistance per cm. of No. 19 German silver wire:—

(*a.*) Set up the apparatus according to the plan outlined above, with about two meters of the wire as the unknown resistance. Connect the ends of the wire to the proper points on the circuit through binding-posts, measuring the length of wire included between them. In connecting the wire and box to the bridge, use pieces of large copper wire as short as possible, and well cleaned at the points of contact. It is also well to have the resistances of the connecting wires used on the two sides of *c* as nearly equal as possible if the position of *d* is near the middle of the wire, as it usually is. Small wire should of course be used for the galvanometer and battery circuits.

Ask to have your scheme of connections verified before beginning work.

See that the galvanometer is not affected by a current in any branch of the circuit except its own.

(*b.*) Find by trial the position of the contact on the bridge-wire which gives zero deflection of the galvanometer. In making a trial, hold the sliding contact down with a gentle pressure, at a point near one end of the bridge, then depress the battery key just long enough to note the direction of the deflection produced. Make a similar trial near the other end of the bridge, and if the deflection is in the opposite direction, the position sought must lie between these limits.

(*c.*) Leaving the connecting wires in position, interchange the wire and the coil, and make a new determination. The sliding contact will now come on the other side of the center of the bridge, so that its position can readily be found; and the mean of the two results from these observations will be nearly free from small errors due to lack of uniformity in the stretched wire and scale, and to the resistance of the connections.

(*d.*) Make a similar pair of determinations for a new length of wire, shorter by a few cm. than the first.

Calculate from each result the resistance of the wire in ohms per cm. Wire cut from the same piece will be used as a known resistance in later experiments, for the determination of small resistances.

(*e.*) Measure the diameter of the wire with the micrometer caliper at several points, and calculate the specific resistance of this sample of German silver—that is, the resistance of a piece 1 sq. cm. in cross-section and 1 cm. long. This value must not be taken as applying to German silver in general, since different samples vary greatly in specific resistance.

25. TESTING EQUALITY OF RESISTANCES.

(*a.*) Secure the rheostat used in Exp. 23, and with a Wheatstone bridge apparatus similar to that used in the last experiment, compare the resistance of each of the six loops with that of the stretched meter. The stretched meter will then constitute the r branch for each case, and the loop used, the x branch. Connections may be readily made by means of the binding-screw plugs which fit the blocks of the rheostat. See that the connecting wires are properly equalized, and use the method of interchange described in Exp. 24 (*c*).

(*b.*) Assuming that the wire on the rheostat is of uniform resistance throughout, calculate the length of each loop, that of the stretched meter being 100 cm.

(*c.*) For each of the combinations of loops used with the voltmeter, calculate the true length of wire, in terms of the above results, and the true position of the slider on this length for each reading. Then reduce the position of the slider to what it would have been had the true length been 400 cm., by proportion. A correction of less than 1 cm. on any one loop may be disregarded.

Plot the results, using as abscissæ the corrected lengths of wire in the main circuit with which the voltmeter was in

parallel, and as ordinates the corresponding deflections of the voltmeter. If the galvanometer obeys the tangent law, show that the plot should be very nearly a straight line, so that any ordinate will be proportional to the corresponding E. M. F.

Show how to convert this relative calibration curve into an absolute one, which will read E. M. F. in volts, by means of the deflection corresponding to the known E. M. F. of the Daniell cell.

26. CALIBRATION OF RHEOSTAT.

The bridge apparatus here used is a more compact form, in which only 50 cm. of the wire is stretched along a scale, the remainder of the meter being made up of two portions of 25 cm. each which may be connected to the first portion by plugs. This connection may be made by means of the two plugs in three different ways, so that the 50 cm. along the scale may be either end or the middle of the meter. The latter arrangement will be most used, and the scale is numbered to correspond to it. For any combination, the terminals of the meter are evidently the blocks which are not connected by a plug, and the binding-screw plugs should be inserted in these blocks, to replace the binding-screws at the ends of the wire in the ordinary form.

A rheostat is furnished, the coils of which have nominal resistances of 1, 2, 2 and 5 ohms. Determine as accurately as possible the resistance of each of these coils, using as known resistances the corresponding coils on a standard rheostat of similar pattern, which has been carefully adjusted.

After finding the resistance of each coil separately, determine that of the four in series as a check.

The rheostat which has thus been calibrated will be used for known resistances in the next experiments.

27. RESISTANCE OF GALVANOMETER COILS.

Spools are provided whose resistances are equal respectively to those of the 50-turn and the 5-turn coils on tangent galvanometer No. 6. Determine accurately the resistance of these spools.

The resistance of the 5-turn coil is so small that the ordinary method can not be relied upon to give good results, since the resistance of the connections is here relatively important. In such cases a substitution method may be employed to advantage. Set up the bridge with the spool as the r branch, and a piece of German silver wire for x, of a length which will bring the slider to a position near the middle of the bridge. Adjust the slider accurately for balance. Then remove the spool and substitute for it a piece of the No. 19 wire, whose resistance per cm. is known, stretching it between the same binding-posts which held the spool, so that the connections are exactly as before. With the slider in the same place, adjust the length of wire between the binding-posts until balance is again obtained. It is then evident that the resistance of the length of wire used is exactly equal to that of the spool for which it was substituted.

This method should be used always for low resistances, as well as for any work where great accuracy is required, since it entirely eliminates errors due to connections, as well as to faults of any kind in the bridge itself.

For the 50-turn coil, use the ordinary bridge method with the calibrated rheostat as known resistance.

From the data of Exp. 19, find the resistance of the battery there used, neglecting the resistance of the connecting wires. Unless the plot was very accurately made, the probable error of this result may be a large fraction of the battery resistance. This method will, however, give accurate results when the bat-

tery resistance is of about the same magnitude as the average resistance which was used in the box in taking measurements for the plot.

28. RESISTANCE OF GALVANOMETER AND BATTERY.

Resistance of Galvanometer—Thompson's Method.

Put the galvanometer in the branch x of the bridge, and let the ordinary galvanometer branch be replaced by a wire. Then it is evident, first, that there will always be a current through the galvanometer when the battery circuit is completed; second, that if the slide be so placed that $r/x=p/q$, where x is the resistance of the galvanometer, no current will flow in the wire cd on making contact to the bridge-wire by means of the slide. If the slide be placed in any other position, there will be a current in cd on making contact, which means a redistribution of currents throughout the system, and hence a change in the current through the galvanometer. When no current flows through cd on making contact, there is no such redistribution, and hence no change in the current through the galvanometer.

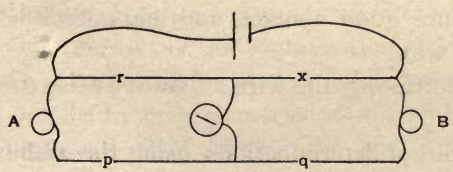
The method therefore consists in adjusting the slide until, on making contact with the slide on the bridge-wire, there is no change in the deflection of the galvanometer. The current from the battery must be allowed to run steadily through the galvanometer, so that the deflection may become steady before making a test; therefore a Daniell cell should be used. The current used will produce so large a deflection that small changes can not be noticed; it can be reduced to the proper amount by connecting the two poles of the cell directly by a wire, to serve as a shunt.

Resistance of Battery—Mance's Method.

The galvanometer and battery b being in their usual positions, let a battery B be put in the branch x. Then for any position of the slider, the current through the galvanometer branch will be the algebraic sum of the currents due to the batteries separately. That is, the effect of one is superposed on that of the other. If the slide be so placed that $r/x=p/q$, where x is the resistance of the battery B, then the current through the galvanometer due to the battery b is zero; so that removing from the system the E. M. F. due to b would not change the galvanometer deflection. It can be shown, further, that for this adjustment, the current through the galvanometer is independent of both the E. M. F. and the resistance in the battery branch. (See Cumming's Theory of Electricity, p. 182.) The battery b may then be replaced by a key, and when the slide is in the proper position, making and breaking the contact with this key will not change the galvanometer deflection.

Thus the only battery used is the one whose resistance is to be measured. Use the Daniell cell as before, and use a shunt in the appropriate place to reduce the galvanometer deflection to a proper amount.

29. RESISTANCE OF BRIDGE-WIRE.



The two branches p and q of the bridge are extended by means of the two unequal known resistances A and B; the battery terminals must then be connected as shown; r and x are unknown resistances, of about the same magnitude as A or B. Then for balance,

$$r/x=(A+p)/(B+q)$$

Now interchange A and B, leaving other connections as before, and find the new positions for balance, for which

$$r/x=(B+p')/(A+q')$$

Add unity to each member of the equations. This gives

$$\frac{r+x}{x}=\frac{A+p+B+q}{B+q} \text{ also } =\frac{B+p'+A+q'}{A+q'}$$

Remembering that $p+q=p'+q'$, show that $q-q'=A-B$.

This is the principle of Carey Foster's method for calibrating a bridge-wire.

(*a.*) For A, use the 1-ohm spool of your rheostat; for B, a short piece of heavy copper wire. $A-B$ will then be the true value of the 1-ohm spool simply. For r and x use a meter of No. 25 G. S. wire with copper terminals, the point c being a binding-post slipped on the wire, so that the ratio r/x may be varied at will. The wire on the bridge used consists of two equal meters of No. 30 G. S. wire, one of which is coiled at one end of the board and the other stretched along the scale. The measurements are of course to be taken on the stretched wire simply.

Make several determinations on different parts of the wire, by varying r/x.

CAUTIONS.—Handle the wire with great care. On account of its small diameter it is easily stretched or broken.

Do not press down on the contact. The weight of the slide is sufficient to secure good contact, and any additional pressure may injure the wire.

Do not slide the contact along the wire. Always raise the slide before moving it.

(*b.*) Make another series of determinations, using the 2-ohm spool in place of the 1-ohm.

(*c.*) From all of the results, calculate the average resistance per cm. of the wire.

The same wire is to be used in the next experiment.

30. ELECTROMOTIVE FORCE.

Use the same wire as in the preceding experiment. The two wires, used by the two sets of observers, and the 50-turn coil of the tangent galvanometer, should be connected in series with two cells of the storage battery, giving an electromotive force of about four volts.

Ask for storage battery connection.

Do not disturb the galvanometer in any way. If it is out of order ask for assistance. Its reduction factor, accurately determined for its present position, is given.

Form a parallel circuit to the wire, consisting of one of the Leclanche cells bearing the number of this experiment, and a Wheatstone galvanometer. Connect one terminal of this circuit to the sliding contact, the other to the key at one end of the board, so that depressing the key will connect the parallel circuit to the coiled end of the bridge-wire.

There is an E. M. F. of about 2 volts distributed along the wire. Therefore an E. M. F. equal to that of the Leclanche, which is less than two volts, exists between the end of the wire and some point along it. If the sliding contact be placed at this point, and if the + terminal of the Leclanche be connected to the same end of the wire as the + terminal of the storage battery, then there will be no current through the parallel circuit. If the Leclanche be connected in the opposite direction, however, there will always be a current through the parallel circuit, for any position of the slider; and this current will obviously be always in the same direction.

(*a*.) In making a test, set the slider at the desired point on the wire, then depress the key at the end of the board just long enough to determine the direction of the deflection produced. A long contact will cause polarization of the Leclanche, and also disturb the current in the main circuit which is being used by the other observers.

Determine first whether the Leclanche is properly connected. Then adjust the slider until the galvanometer indicates zero current, and read its position. Read the tangent galvanometer, reversing its deflection as usual. This reading, as well as the final careful adjustment of the slider, should be made when the other pair of observers are not making trial adjustments which will disturb the main current.

(*b.*) From Ohm's law, calculate the E. M. F. between the end of the wire and the sliding contact, which is equal to that of the Leclanche.

Make sure that this method is well understood before going on, as mistakes with the standard cell might be dangerous.

(*c.*) Repeat with the standard cell furnished. This is a cell used as a standard of electromotive force. Its constancy depends upon careful handling, and upon having only minute currents sent through it.

The terminal coming from the upper end of the cell is the zinc or negative, corresponding to the zinc of the Leclanche. Knowing also that the E. M. F. is very nearly one volt, it will be possible by a little calculation to set the slider very near to the true point at the start.

Never use a standard cell without such a preliminary test with an ordinary cell. If it is impossible to approximate closely to the true position of the slider, a resistance of several thousand ohms should be included in series with the cell to protect it against currents of dangerous strength.

(*d.*) How could the E. M. F. of any cell be determined in terms of the known E. M. F. of the standard by this method, without using the tangent galvanometer?

Determine in this way the E. M. F. of a bichromate (Grenet) cell, if one is to be had. In using this cell, the zinc should be lowered into the acid only while a current is wanted.

(*e.*) If there is time, let each set of observers determine, as in (*c*), the E. M. F. of the standard previously used by the other.

A wire or other resistance used as in this experiment is called a potentiometer.

31. BATTERY RESISTANCE.

Let E be the E. M. F. of a cell measured when it is sending no current, as in the last experiment. Let e be the E. M. F. measured between its terminals when it is sending a current c through an external resistance r. Then in this latter case, E is evidently the E. M. F. which sends the current c through the whole resistance in circuit, including that of the battery; while e is the E. M. F. which sends the same current through the external resistance r.

Then calling the resistance of the battery b, $E=c(r+b)$, $e=cr$. From these equations b can be found if E and e are known, and either c or r. In this experiment we use known resistances. Use a Daniell cell and resistance box, and measure the E. M. F.'s on a potentiometer supplied with current from storage battery. The potentiometer is thus used as a voltmeter. Ask for storage battery connections.

(*a.*) Determine the E. M. F. of the Daniell by comparison with one of the standards whose value was determined in the last experiment. Use the Daniell first, remembering that its E. M. F. is about 1.1 volts, in order to get the connections right and the slide at about the right point, for the standard.

The result here obtained for the Daniell is evidently the value of E required.

(*b.*) Having the Daniell connected to the potentiometer as at first, connect its terminals also to those of the resistance box, using connecting wires of low resistance. The potentiometer may now be used as a voltmeter, to determine the E. M. F. existing between the terminals of the cell while it is sending a current through the known resistance in the

box. In this way find the values of e for a number of resistances, from 10 units down to 0.5. After each determination, disconnect the resistance box and test the value of E. The reading with the standard cell should be repeated at about the middle of the series, and again at the end, in order to make sure that the storage battery current has remained constant throughout.

(*c*.) Calculate the resistance of the battery, and also the current flowing through it, for each case.

(*d*.) Plot the results obtained in (*c*), so as to show the relation between the resistance of the cell and the current passing through it.

32. CALIBRATION OF A COPPER-WIRE THERMOMETER.

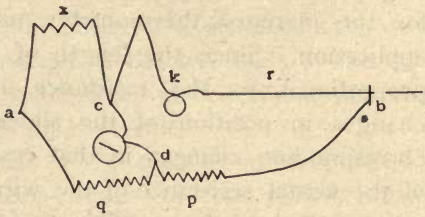
The electrical resistance of all conductors changes with change of temperature, and for pure metals the change is found to be very nearly proportional to the change of temperature. In this experiment the rate of change of resistance with temperature is to be determined for a copper wire, which may then be used as a thermometer if necessary. If the calibration curve be a straight line, it is evident that the thermometer can safely be used for temperatures beyond the limits of the mercury thermometer. Another advantage of this form of thermometer is that the average temperature of any body may be determined very accurately, when it is not at a uniform temperature throughout, by distributing the copper wire uniformly around or through it.

The wire used is No. 32 insulated copper, of about 4 ohms resistance, wound on a sheet of mica, its terminals soldered to No. 22 lead-wires.

A spool is furnished on which are wound two equal resistances. If these be made the branches p and q of a

bridge arrangement in which the thermometer is the branch x and the bridge-wire, measured from one end to the sliding contact, is the branch r, then it is evident that if r can be adjusted, by means of the sliding contact, so as to give no current in the galvanometer circuit, the resistance in r is exactly equal to that of the thermometer wire, and its lead-wires. In order to eliminate the effect of these leads, a pair of "compensating leads," consisting of a simple loop of wire of the same size and length as the thermometer leads, is wound with them, so that the resistance of the two pairs of leads will be the same under all circumstances. If these compensating leads be put in r, in series with the bridge-wire, the resistance of the bridge-wire in r will then be equal to that of the No. 32 wire of the thermometer simply.

The two 25 cm. lengths on the bridge need not be used. The 50 cm. along the scale is to be extended by a spool k equal in resistance to 250 cm. of the wire, so that the actual length of wire up to the sliding contact is the length on the scale added to 250.



In setting up the arrangement, notice that the point a is the junction of one thermometer lead with one end of the spool carrying p and q, b is the binding-screw on the sliding contact, to which the other end of the spool is attached, c is the junction of the second thermometer lead with one of the compensating leads, the other being connected to the coil k at the end of the bridge, and d is the junction of p and q.

The thermometer leads are tied with a piece of twine near the ends, to distinguish them from the compensating leads.

(*a.*) Use a kettle for a water-bath in which to immerse the

copper thermometer and the attached mercury thermometer. Record the position of the slider for temperatures at intervals of about 5° through the range from 20° to 40°. For each reading keep the temperature steady, within 0°.1, and the bath well stirred until the position of the slider for balance remains constant, showing that the wire has attained the same temperature as that indicated by the thermometer. Take care to make the contacts in the battery circuit as short as possible, in order to avoid heating the thermometer wire by the testing current.

Take a similar series of descending readings, at about the middle points of the temperature intervals previously used.

(*b.*) Plot the observations, using temperatures as abscissæ and changes in position of slider as ordinates, each on as large a scale as the paper will permit. The calibration curve for the mercury thermometer used will be furnished on application. Since the length of the bridge-wire is always proportional to the resistance of the thermometer wire, changes in position of the slider will be proportional to corresponding changes in that resistance; and a knowledge of the actual resistance of the wire is unnecessary.

(*c.*) Calculate the coefficient of increase of resistance per degree, in terms of the resistance at 0°.

(*d.*) Calculate the temperature at which the resistance of the wire would become zero. What must you assume?

33. STUDY OF POLARIZATION EFFECTS.

Use the same voltmeter as in Exp. 23, and see that the proper resistance coil is connected in series with it. Also use a Leclanche cell which bears the number of this experiment, and no other.

In this experiment the closing of a key produces a deflection of the voltmeter corresponding to an E. M. F. which is

changing rather rapidly, so that a reading must be obtained as soon as possible. The needle, however, does not come to rest until after several vibrations; so that the best plan is to read three consecutive turning-points (the first three if possible) and calculate from them the resting-point, as was done with the balance. A little practice at this before beginning the experiment will be of advantage.

(*a.*) Connect the terminals of the cell directly with the terminals of the voltmeter, and so get a reading which is proportional to the total E. M. F. E of the cell. It may be necessary to move the voltmeter coils farther away from the needle in order to get a deflection which can be read on the scale. This deflection should be at least 3 cm. from the end of the scale, for convenience in reading turning-points later on.

Throughout the succeeding series of observations the voltmeter should remain connected to the terminals of the cell, except that it should be disconnected at convenient intervals to check the zero reading on the scale.

(*b.*) Connect the terminals of the cell through a spool of 2 ohms resistance and a break-circuit key (one which breaks connection instead of making it on depressing the lever). Complete this parallel circuit at a noted time and immediately read the voltmeter deflection e by means of three turning-points. Be careful not to connect the cell in such a way as to send a current through it until ready to begin observations.

(*c.*) At the end of five minutes read e again, disconnect the resistance, by means of the break-circuit key, and as quickly as possible read E, by means of three turning-points. This reading must be taken quickly because E, which has been reduced by polarization caused by the passage of the current, immediately begins to return to its former value.

(*d.*) Re-connect the resistance, and note the time at which e again has the same value as that read in (*c*). Count from

this another 5-minute interval, then repeat the readings as in (*c*). By this means the readings obtained are very nearly the same that they would have been if no time had been lost in taking them, so that the current could flow continuously.

Continue the readings in this way until four periods of 5 minutes each have been covered.

(*e*.) Leaving the resistance disconnected, take readings of E at 5-minute intervals for about 45 minutes.

At some time during this interval, secure if possible the Leclanche cell whose E. M. F. was determined in Exp. 30, and by getting the voltmeter deflection corresponding to its E. M. F., obtain a factor for reducing your readings to volts.

Why could not a standard cell, whose resistance is about 1,000 ohms, be used for this purpose?

(*f*.) Plot a curve with times as abscissæ and corresponding values of E as ordinates, for the whole time of the experiment. Remember that during the first part the 5-minute intervals only are to be counted.

Calculate, as in the last experiment, the resistance of the cell from each pair of values of e and E, tabulate the results, and show that for this purpose the scale-readings corresponding to E and e may be used without knowing their values in volts.

34. WRITTEN EXERCISE—ELECTRICITY.

(1.) Arrange the details of a method for calibrating the sensitive galvanometer whose resistance was determined in Exp. 28, using your tangent galvanometer to determine the strengths of the currents used, and dividing these currents so as to send known fractions through the sensitive galvanometer.

The curve obtained should read amperes directly. Will this probably be a tangent curve?

(2.) Having given this calibration curve for the sensitive galvanometer, show how you could use it as a voltmeter.

(3.) Show that the scale readings in Exp. 23 are only approximately proportional to the tangents of the corresponding angles of deflection, using the simple law of reflection at a plane mirror.

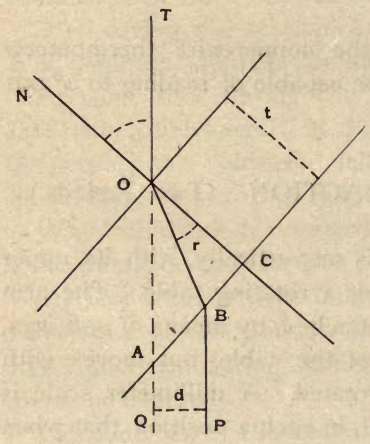
(4.) Show that the Carey Foster method could be used to find the difference between two nearly equal resistances, A and B.

(5.) Show how to modify the copper-wire thermometer apparatus in 32 so that it will be capable of reading to 0°.001 through a range of 5°.

35–36. INDEX OF REFRACTION. (Two Periods.)

A small piece of plate glass is set vertically, with its upper edge horizontal, at the center of a rotating table. The arm to which the glass is directly attached, by means of soft wax, can be turned independently of the table, but moves with the table when the latter is rotated. A millimeter scale is placed with its divisions vertical, in such a position that when a telescope at the same height as the upper edge of the glass is focused on the scale, its divisions will be seen partly through the glass plate, and partly above its upper edge. The scale should be normal to the line of sight, with its middle division, marked zero, behind the middle of the glass plate. Set the eye-piece of the telescope so that the cross-wires are at an angle of 45° with the vertical, and with their intersection on the zero line above the glass. The image seen in the telescope will then consist of two parts, one formed by light coming through the glass plate, the other by light coming through the air above the plate. These two images will appear to coincide when the plate is normal to the line of sight; but when the plate is rotated in either direction about a vertical axis, one portion of the image is displaced with reference to the other. For a certain angle of rotation,

the lines of the scale will again appear to be continuous, instead of broken. This evidently means that one portion of the image has been displaced with reference to the other by 1 mm. Continuing the rotation, the lines of the scale will again appear to be continuous for displacements of 2, 3, etc., mm.



In the figure, PBOT represents the path of the pencil, from the scale to the telescope, by which part of one scale division is seen through the glass; QAOT, that by which part of the adjacent division is seen above the glass. The two paths coincide after leaving the glass, so that the two parts of the two lines appear to coincide and form one line in the image.

t is thickness of plate.

d is distance which one image is displaced with reference to the other.

i is angle of incidence (or emergence).

r is angle of refraction.

The index of refraction is to be obtained from the formula $n = \sin i / \sin r$.

All of the above quantities will be determined directly, except r, which can be obtained from the relation $\tan r = \tan i - (d/t \cos i)$. Show the truth of this relation from the figure.

(*a.*) To determine the values of i corresponding to displacements of 1, 2, 3, and 4 mm. Either the arm to which the glass is attached, or the whole table, can be rotated by the observer at the telescope by means of a wooden rod with a peg at the end, which can be set in one of the holes made for the purpose.

Although i may be observed directly, a better result will be obtained by measuring $2i$. To do this, set the plate so that a displacement of 1 mm. in one direction is obtained, then read the angle through which the table must be rotated to cause an equal displacement in the other direction.

It will soon be seen that the accuracy of a single setting is not very great, so that it is desirable to average a large number of settings. This can be done without reading each setting, as follows: Set the circle so that the index reads zero; set the glass, by means of the movable arm, to give a displacement of 1 mm.; turn the table until an equal displacement in the opposite direction is secured; leaving the table in this position, turn the glass back to its original position by means of the movable arm; again turn the glass into its second position by means of the table. It is evident that each time the operation is repeated, the table is turned through an angle $2i$; and thus any number of observations may be automatically added.

Make a series of determinations in this way until the sum of the angles reaches three or four times 360°. The final reading should be taken at a point as near to the zero of the circle as possible, which will reduce the effect of errors in the graduation or mounting of the circle. The second observer should note the number of settings made, and the number of times the zero of the circle passes the index. Calculate the mean value of i for the series.

In this way let each observer make a determination of i for each displacement of 1, 2, 3, and 4 millimeters.

(*b.*) To determine t, by means of the Optical Lever.

The optical lever is a short lever of brass resting by three points on a bed-plate of brass. Two of the points, at one end, rest in minute conical depressions in the bed-plate, which keep them in definite position, and serve as the fulcrum of the lever. The perpendicular distance from the third point to the line joining these two points is the effective length of the lever.

The distance through which the third point is raised when any object is placed under it, or the thickness of the object, is to be calculated from the length of the lever and the angle through which it is rotated.

This angle is to be measured by means of a modification of the telescope and scale method. A scale is set in a vertical position at a distance of 75 to 100 cm. in front of the mirror which is attached to the lever. A slider attached to the scale is pierced with a small round hole, and has on the side toward the mirror a horizontal line whose direction passes through the center of the hole. Adjust the relative positions of scale and lever so that when the slider is at the proper height, the reflected image of the horizontal line can be seen in the mirror, on looking through the hole. Adjust the slider until the image of the line appears to bisect the small round ink-spot near the center of the mirror. The adjustment can be made more closely if the eye be held a short distance from the hole, and so that the spot on the mirror appears to be exactly in the center of the hole. It is now evident that the normal to the mirror, at the center of the spot, passes through the center of the hole.

The scale should now be vertical, and the normal to the mirror horizontal, that they may form two sides of a right triangle. Adjust the former by sighting on window casings or other convenient vertical lines. Test the latter by measuring from the table the height of the line on the slider and of the spot on the mirror, and make any necessary adjustment by means of the screw to which the third point is attached. Having these adjustments made, read the position of the slider by means of the index.

The thickness of the plate is only needed over the portion actually used in (*a*). The settings made should therefore be confined to this portion, and should cover it with some attempt at uniformity, so that the mean thickness of the plate as used will be determined.

Carefully lift the third point of the lever, and insert the plate, letting it rest on the three projections from the bed-plate. See that the two points at the other end of the lever have not been disturbed from their position, then adjust and read the slider as before. Make several settings of the slider for different points over the desired area of the plate, then remove the latter and check the zero reading.

Measure the horizontal distance from the line on the slider to the face of the mirror, and calculate the mean angle through which the lever has been rotated.

Repeat for at least two other distances of the scale from the mirror. Note that if the distance be made just 1 meter, the difference between the two readings of the slider gives the tangent of the angle directly.

Calculate the mean angle from the whole series.

To find the length of the lever, lay it on the table with the points up, and lay on them a half-millimeter scale ruled on glass, ruled side down. Set the two points at one end of the lever in the long zero division, and read the position of the third point as closely as possible with a magnifying glass. This evidently gives the desired distance, since the zero division is perpendicular to the length of the scale.

This gives all the data needed for calculating the thickness of the working portion of the glass plate.

(*c.*) Calculate the index of refraction of the glass, from each pair of values of i and d obtained in (*a*), and find the mean of these results.

37–38. SPHEROMETER. (Two Periods.)

Radii of Curvature of Lens Surfaces.

PRELIMINARY.—Testing vernier calipers.

Secure the billiard ball whose volume was determined in Exp. 5, and from that volume find the mean diameter of the

ball (Whiting's Tables, 3H). This gives a standard of length whose value is independent of any direct measurement on a scale. (See Whiting, p. 72.) By measuring the diameter of the ball with the vernier calipers, the scale of the calipers may be compared with this standard.

As the ball is not a perfect sphere, it will be necessary to measure a number of diameters in different directions, uniformly distributed, in order to get a result which may be compared with the diameter calculated from the volume. In order to get a uniform distribution of the measurements, draw lightly in pencil on the ball two great circles at right angles, and a third perpendicular to both. The intersections of these will give three diameters, and points on each circle midway between the intersections will give six more. Four others may be taken connecting the centers of the triangles into which the surface has been divided.

Only one pair of calipers is available, so that while one set of observers is using it, the other should be taking the spherometer readings in (*a*) and (*b*).

In using the calipers, great care should be taken not to strain the jaws. Ask for special directions as to the necessary precautions. Make a coarse adjustment by taking hold of the movable jaw (not the small slide attached to it) and sliding it along the scale. Then clamp the small slide, and make the final adjustment by means of the slow-motion screw, turning it until the object is touched lightly by both jaws, but not held firmly between them.

To set on a given diameter of the ball, hold it with one marked end of the diameter against the fixed jaw, just inside the end. Then adjust the movable jaw until, on moving the ball slightly back and forth, it just grazes the corresponding point on this jaw. Never clamp the ball so tightly that its weight can be supported by the calipers. The accuracy of the results will depend largely on the uniformity of the pressure with which these settings are made.

After making the settings on the ball, close the movable jaw up against the fixed jaw with as nearly as possible the same pressure used on the ball, and determine the zero error. If any is found, allow for it on the measurements taken.

Find the factor by which the mean diameter in terms of the caliper scale must be reduced to the calculated value, and if this factor differs from unity by an appreciable amount, use it in future work.

(*a.*) Pitch of spherometer screw.

A rotating arm is provided which slips over the point of the spherometer screw. By means of this, adjust the upper brass ring so that its axis coincides with the axis of rotation of the screw, and clamp it in that position by means of the small clamp-screws underneath.

Fasten a small piece of plate glass to a larger piece with soft wax, making sure that the surfaces are clean and accurately in contact. Set the plate on the ring of the spherometer, with the attached piece downward, and while holding it down with one hand, turn the screw upward by means of the milled head underneath the disk. Never turn the screw by means of the disk itself. The screw turns very easily, so that the moment of contact can be felt, and care should be taken not to strain the screw by turning beyond this point. Find the number of turns of the screw corresponding to the thickness of the piece of glass at two selected points near its edges, by setting the screw first on the selected points, and then on the plate when the piece has been removed.

Measure the thickness of the piece at each of the two points, making several settings of the calipers in each case. Calculate the pitch of the screw, or the distance in centimeters which its point advances for one revolution.

Also measure with the calipers the internal diameter of the upper ring on the spherometer, and check the measurement with the glass scale used in the last experiment. The radius

of this ring, which is the perpendicular distance from the axis of the screw to the inner edge of the ring, is called the "Span" s of the spherometer.

When you have finished with the calipers wipe them carefully with a dry cloth before putting them in the case, to guard against rust.

(*b.*) Set the ball in the ring of the spherometer, and bring up the screw as in (*a*) against its lower surface. In this way make a setting on each of the previously marked points, in order to find the mean distance d from the point of the screw, when thus resting against the surface of the ball, to the plane of the upper surface of the ring.

To calculate the diameter of the ball from these data, consider a section of the ball made by a plane through the common axis of the screw and the ring. In this figure, if D be the vertical diameter of the ball, show that

$$s^2 = d\,(D - d)$$

If the value of D, calculated from this formula, agrees closely with the value first obtained from the volume, it is evidence that the constants of the spherometer have been accurately determined in terms of your absolute length standard, and that the method of calculation is well understood.

(*c.*) Find the radius of curvature of each surface of the given lens from a number of readings on different parts of the surface.

The same lens is to be used in several succeeding experiments. When not in use it should be kept in the rack provided for the purpose. Be careful at all times to avoid scratching the surfaces of the lens in using.

39. FOCAL LENGTH OF LENS.

The focal length of the lens is first to be determined by the method of conjugate foci. Fix the lens on one of the slides

of the optical bench, which is fitted to hold it. A large screen at one end of the bench is fitted with fine threads stretched across a small hole, to serve as objects. The similar threads stretched across the hole in the small screen on the second slide of the bench are used to locate the image, formed by the lens, of the object.

Move the two slides as near to the large screen as the bench will allow, and adjust the two screens so that the centers of the openings and the center of the lens shall be on the same straight line parallel to the bench. The centers will then remain on this line as the slides are moved. This adjustment can be made well enough by eye, or by rough measurement from the bench.

(*a.*) For each observation, the distance of the lens from each screen is needed; and it is evident that these distances can not be directly obtained by reading the positions of the slides on the meter scale. To provide the means of getting the true distances from any set of readings, set the slides at any convenient positions, read their indices, and measure with a beam caliper the distance from each set of threads to the corresponding lens surface. Take three sets of measurements for different positions of the slide.

The lens is assumed to be a thin lens, or one whose thickness may be neglected. The approximation arising from this assumption will be less, for the double convex lens used, if the measurements are made from the center instead of from the surfaces. The thickness of the lens, for this purpose, can be measured with sufficient accuracy as follows: Put two small wooden blocks on the two slides, setting them so that the adjacent surfaces are in contact, and read the distance between the indices. Then separate the slides, insert the lens between the blocks, and read the distance again.

(*b.*) Bring the image screen back nearly to the opposite end of the bench from the object, and bring the lens toward it until,

on looking toward the lens from about 30 cm. behind the image screen, the image of the object is seen through the hole in the screen. Adjust the lens then until the image seems to be in the same plane as the threads in the screen, tested by seeing that there is no parallax between the two on moving the eye from side to side.

To make a closer adjustment, hold a magnifying glass so that the threads are clearly seen. If the image be not in the same plane, it will not be clearly in focus at the same time, and any remaining parallax will be magnified. Find the object, distance u.

Leaving the lens where it is, so that u will remain the same, move the image screen and then readjust it. Practice in this way until settings can be made which agree within 1 or 2 mm., then from the mean of several settings find the image distance v.

Move the lens toward the object until, by rough trial, v is found nearly equal to u. Then determine u and v as before.

(*c.*) Lay off on co-ordinate paper the first pair of values of u and v along the axes of X and Y respectively, on a scale as large as possible, and connect the two points by a straight line. Do the same for the other pair of values. Draw the lines accurately, with a fine pointed hard pencil.

Write the equation of either of the lines, and show that if

$$1/v + 1/u = 1/f,$$

the point, each of whose co-ordinates is f, will lie on this line, and hence will be the point of intersection of two such lines. It will of course also lie on the line making an angle of 45° with each axis. Draw this 45° line. Then the best value of f will be found by locating the point which represents the average of the points in which the u, v lines intersect the 45° line.

Find several additional pairs of values of u and v, choosing them so that the resulting lines will cover as wide a range in direction as possible, and use the average from all. For some

of them, v should be made greater than u, so as to give a magnified image.

If this magnified image is indistinct, so that it is difficult to make an accurate setting, cut a hole about 1 cm. in diameter in a piece of paper, and put it in front of the lens so that only the central portion of the lens will be effective in forming the image.

(*d.*) Move the opening in the piece of paper out near one edge of the lens, so that the image is now formed by a portion of the lens away from the center. Determine the focal length as in (*c*) for this part of the lens. Then explain the advantage of a diaphragm with a small central opening for securing a distinct and definite image; and see also that in looking at the image with the eye, the image formed by any desired portion of the lens can be seen by holding the eye in the appropriate position. The office of the diaphragm in this case is merely to make it certain that the eye sees the desired image and no other.

40. FOCAL LENGTH AND INDEX OF REFRACTION FOR RED AND BLUE LIGHT.

Since the focal length of a lens depends upon its index of refraction, which varies for different wave-lengths, it is evident that the value of f determined in the last experiment was an average value for the brighter portion of the spectrum of the light used. In order to determine f for two fairly definite colors of the spectrum, red and blue, put in front of the object threads a piece of blue glass, which, it will be remembered, transmits some red light as well as blue. Illuminate the threads by a kerosene lamp placed behind them. This light, being richer in red as compared with blue than ordinary daylight, will give more nearly equal brightness in the red and blue transmitted by the glass. We will now have two images

formed by the lens—one by red and one by blue light. On setting the image-screen and applying the magnifying glass it will be seen that there are two positions of the screen which give a clear image. At one position the threads, and the margin of the aperture in the screen, appear red and the spaces bluish; at the other the threads and margin appear blue and the spaces reddish. Decide as to which image is formed by blue and which by red light, and explain the color phenomena in the two cases.

For convenience, the magnifying glass is attached to the image-screen, so that it can be focused on the thread and moved with the screen, or turned one side for a rough setting.

(*a.*) Determine, by the method of the last experiment, the focal length of the lens for red and for blue light. Locate both images for each position of the lens, and so carry on both series at once.

(*b.*) From the radii of curvature of the lens surfaces, and f as found in the last experiment, calculate its index of refraction for the light there used. In the same way, from the data obtained in this experiment, calculate its index of refraction for red and for blue light.

41. INDEX OF REFRACTION OF A LIQUID.

(*a.*) Inclose a little water between a piece of plate glass and the lens previously used, keeping it in place by a cell made from a piece of sheet rubber with a round hole cut from its center. Mount the whole on the optical bench, and determine the focal length of the combination, for daylight. Use the following method: —

For a given position of the lens, let $u+v=l$, the distance between the screens. Then leaving the screens fixed, move the lens to another position, such that $u_1=v$ and $v_1=u$. If the

first image was reduced, the second will be enlarged; and the distance through which the lens was moved (read directly on the scale) is $v - v_1 = v - u = a$. Show then that $f = (l^2 - a^2) / 4l$. This does not involve any measurements to the lens surfaces, which might be awkward in this case.

The plate glass used is of the same piece as that whose index of refraction was determined in Exp. 36. If u above include this plate glass, show how to correct it so as to get the value which u would have in air; and show that this correction should be applied to l as measured above.

(*b*.) Calculate the focal length and index of refraction of the liquid lens.

42. INDEX OF REFRACTION OF LENS—MICROSCOPE METHOD.

The measurements to be taken are the same as in the measurement of refractive index of a plate—namely, the real thickness, and the apparent thickness, of the lens, both taken along its axis. It is evident that the formula for the plate will not apply here, since the wave-front in the air, after refraction at the upper spherical surface of the lens, will differ in form from that due to refraction at the plane upper surface of the plate. By means of the known relations for refraction at a single spherical surface, show that

$$n = \frac{AB(r - Ab)}{Ab(r - AB)}$$

where AB = real thickness of lens
Ab = apparent " " "
r = radius of upper surface.

Set the lens, resting on a piece of plate glass, on the stage of the microscope, with its axis as nearly as possible in the axis of the microscope. A little chalk dust rubbed with the finger from a crayon and smeared very lightly on the upper surfaces of the lens and the plate glass, will provide objects on which to focus the microscope. Focus roughly on the

upper surface of the lens by sliding the tube in its clamp, then clamp the tube and focus more closely by means of the micrometer screw, which moves the tube vertically. See that the tube is parallel to the screw, and that it can be moved downward through a distance fully equal to the thickness of the lens.

In making a setting, always move the screw in the same direction to the desired point; and if that point be accidentally passed, turn the screw backward some distance, in order to approach the point again from the original direction. This precaution is necessary because there is likely to be some lost motion in changing the direction of rotation of the screw.

Use the parallax test, as far as possible, to decide whether the image is accurately in the plane of the cross-wires.

The pitch of the screw is 0.025 cm.

After practicing until settings can be made which agree fairly well, let each observer make a series of settings on (*a*) the upper surface of the lens, (*b*) the upper surface of the plate as seen through the lens, and (*c*) the upper surface of the plate after removing the lens.

From these find AB and Ab, and calculate n, the index of refraction.

Tabulate all the indices of refraction which have been found.

43. WRITTEN EXERCISE. LENSES.

1. Show how the optical bench, as used in Exps. 39, 40, corresponds to the type of (*a*) the astronomical telescope, or (*b*) the compound microscope, according to the position of the large lens with reference to the two screens.

2. Taking either of the cases in (1), trace the light from the object which falls on the effective aperture of the large lens, until it finally forms an image of the object on the retina of the eye; indicating the position and kind of image formed by refraction at each lens of the system.

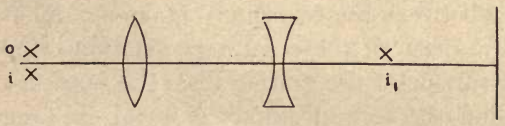
3. Describe the essential improvements in the working telescope and microscope over the optical bench types.

4. Certain approximations are made in deriving the fundamental formulæ relating to lenses which you have used in Exps. 39–42. State these approximations, and show that under the working conditions, their use is justified.

5. Explain the theory of the following method of finding the focal length of a diverging (concave) lens:—

Threads stretched across an aperture in a screen, and brightly illuminated, form the object *o*. This is put at one end of an optical bench, next to it a converging lens, then the diverging lens, and at the other end of the bench a plane mirror, facing the object, and with its plane at right angles to the axis of the bench.

The lenses are now so adjusted that the light from the object, passing through the lenses to the mirror, and there reflected back so as to again pass through the lenses in the reverse direction, forms an image *i* of the object on the screen beside the aperture—that is, the image is formed in the same plane as the object.



If now the diverging lens be removed, the converging lens will form an image i of the object at some point beyond the place where the diverging lens was. This image may be located by any of the usual methods, and its position was the principal focus of the diverging lens when that was in position. Then of course the distance from this point to the point where the lens was, is its focal length.

44. DIFFRACTION GRATING.

A monochromatic light is required. For this purpose use a Bunsen burner with an asbestos cap which can be

soaked in a solution of sodium chloride, so as to give a strong sodium flame. Set in front of this the brass screen, with its plane vertical and the slits horizontal. In use, the light is allowed to shine through one slit on each side of the central vertical line of the screen, the third slit being covered.

The grating is to be mounted in a slide on a meter rod, with the ruled surface toward the screen and the lines parallel to the slits. The rod is to be supported by a clamp so that it will carry the grating along a line perpendicular to the screen at the lower slit. On looking at the slits through the grating, a series of diffracted images of each slit is seen. The two sets of images move relatively to each other as the grating is moved back and forth; and a position of the grating may be found for which one of the images in one set appears to form a continuous line with one in the other set. If the lines do not quite meet, it is evidence that the lines of the grating are not quite parallel to the slits.

(*a.*) Using the two slits which are closer together, set the grating so that the first image of one slit coincides, in the way above indicated, with the first image of the other slit, at the point half-way between the two slits. Make a number of settings, and for the mean of these settings determine the distance of the ruled surface of the grating from the screen.

(*b.*) Repeat (*a*), using the second diffracted image of each slit, instead of the first.

(*c.*) Repeat (*a*) and (*b*) for the pair of slits which are wider apart.

(*d.*) Measure the distance between the slits with the ½ mm. glass scale. Determine the mean distance from measurements on the edges, taking a number of readings, on different parts of the scale, for each distance.

(*e.*) Assuming the wave-length of sodium light to be 0.0000589 cm., determine the distance apart of the lines in the grating. Explain fully your method of calculation, and show that it applies to this case.

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